INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1880.

PUBLISHED BY THE INSTITUTION,

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CONTENTS.

1880.

1880.

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Edward A. Cowper, ... London.

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Robert Napier, ... (*deceased* 1876).
John Penn, F.R.S., ... (*deceased* 1878).
George Stephenson, ... (*deceased* 1848).
Robert Stephenson, F.R.S., ... (*deceased* 1859).

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Institution of Mechanical Engineers.

MEMOIRS

OF MEMBERS DECEASED IN 1879.

CHARLES CAMMELL was born in Hull on 10th January 1810, and died in London on 12th January 1879, having just entered his seventieth year. After serving an apprenticeship to an ironmonger in Hull, he came to Sheffield in 1830, and entered the service of Messrs. Ibbotson, of the Globe Works, as commercial traveller. In 1837, in conjunction with Messrs. Thomas and Henry Johnson, he started business in Furnival Street, as steel and file manufacturers, under the style of Johnson Cammell and Co. In 1845, finding their premises insufficient, they removed to some fields near the Sheffield and Rotherham railway station, now occupied by the enormous Cyclops Works. In 1852 Mr. Thomas Johnson died, and Mr. Edward Bury became a partner in the works. He retired in 1855, and the firm then assumed the style of Charles Cammell and Co. In 1861 the manufacture of rails and railway material was added; and in 1863 that of armour plates. The business had now grown so large as to necessitate further extension and development of the works. Accordingly in 1863 additional works were erected at Grimesthorpe, near Sheffield: and in 1864 the firm was converted into a Limited Company, Mr. Cammell taking the position of chairman, which he retained to his death. Under his management, and that of Mr. George Wilson as managing director, the success of the Company, in all departments, was continuous and brilliant. In 1865 they acquired the Yorkshire Iron and Steel Works, at Penistone, and in 1873 the Oaks Colliery, near Barnsley, thus becoming the possessors of their own raw material.

The present position and business of the Company may be thus described. At the Cyclops Works, covering nearly eleven acres, are manufactured all kinds of crucible steel, Bessemer steel, and iron. Armour plates are also made here, and have been rolled to a thickness of 24 in., and to a weight of 45 tons. A special product is Mr. Alexander Wilson's compound armour plate, consisting of an iron plate with a steel face welded on to it (see Proceedings 1879, p. 64). So much success has attended the development of this process, that the Admiralty and the War Department have definitely adopted the system in place of iron alone. At the Grimesthorpe Works, railway springs, tyres, and buffers, steel forgings, and steel boiler-plates are manufactured upon a large scale. In the forge are several heavy hammers, one of 25 tons weight, which is used in the forging of heavy gun-blocks, marine and mill engine-shafts, &c. Here also is the steel foundry, one of the largest in the kingdom, capable of turning out steel castings up to 35 tons weight, and having amongst other appliances a travelling crane to lift 60 tons. The Penistone Works are entirely devoted to the production of Bessemer steel from the converter, and its manufacture into rails, axles, tyres, forgings, and ship-plates. The collieries comprise about 1100 acres, and are capable of raising about 10,000 tons of coal per week, the greater part of which is consumed at the various works of the Company. Exclusive of these, the total area of land occupied by the works of the Company is nearly 60 acres. Between 5000 and 6000 men are employed, and the weekly production of iron and steel amounts to fully 3500 tons.

For some years before his death Mr. Cammell had retired from the active management of the business, but he continued to attend the directors' meetings, &c. His whole heart was in his works, neither politics nor local matters interesting him greatly; and his success was mainly due on the one hand to his unwearied industry and perseverance, and on the other hand to his skill in selecting partners and subordinates specially qualified to assist him in the development and carrying on of his enormous business. He became a Member of the Institution in October 1847, the first year of its existence; but he never took any part in the proceedings.

SAMPSON LLOYD FOSTER, second son of the late Mr. Sampson Foster, was born at Fakenham on 7th August 1831, and died at Ealing on 31st March 1879. He was for some time an active partner in the firm of Lloyds Fosters & Co., Old Park Iron Works, Wednesbury. He retired from the firm in 1866, and from that time was chiefly engaged as director of several mining and other companies. He became a Member of the Institution in 1861.

WILLIAM FROUDE, LL.D., F.R.S., was born in 1810, at Dartington Parsonage, Devonshire, the house of his father the Ven. R. H. Froude, Archdeacon of Totnes. He was educated at Westminster School and at Oriel College, Oxford, where he took a first-class in mathematical honours in 1832. He then became a pupil of Mr. Henry Robinson Palmer, Civil Engineer. In 1837 he became an assistant of Mr. Brunel, and was engaged on the works of the Bristol and Exeter Railway until the completion of the line in 1844, being, during the latter portion of the time, Resident Engineer of the line on the Devonshire side of the summit tunnel. For family reasons he shortly afterwards retired from the active pursuit of his profession; but on occasion he assisted his friend Mr. Brunel in engineering matters, of which perhaps the most important was the investigation concerning friction, which he made in reference to the launch of the *Great Eastern* steamship. By trial of a specimen of the iron sliding surfaces, and by automatic records of the movements of the ship herself, Mr. Froude proved that the friction of the sliding surfaces was not independent of the velocity as commonly supposed, but became much less as the velocity increased. It was also in connection with the *Great Eastern* that he undertook the enquiry into the causes of the Rolling of Ships, which he continued during the subsequent twenty years. The mechanical possibility of the trochoidal theory of ocean waves, the effect of the cumulative action of more or less synchronous waves upon a ship, and the modifying effects of the resistance which a ship offers to rolling, were worked out by him. He also devised apparatus for determining the characteristic qualities of different ships, by recording their behaviour when set rolling in still water, or when rolling in actual waves at sea.

form the several elements of use and wast steam power for the propulsion of ships: h the screw propeller in its effect on the stream a ship: finally he investigated the circumstar propeller operates, and the loss of power d rotating in the water. It was in connection Resistance of Ships that he undertook for t the construction and management of an exp at Torquay, for the trial of models of ships series of exhaustive experiments on the for determined the resistance of models of mos built for the Royal Navy.

Mr. Froude was a member of the Committ of War in 1870, and of the Committee on He was an able and exact workman, and inventive powers are exhibited by the desig apparatus, especially of the rolling-recordi machinery for making models (see Proce and of the several governors and dynamom experiments; also in a marked degree by principle of the marine-engine dynamometer, the Bristol Meeting of the Institution, 18 p. 237). In addition to the great services h

Agricultural Society, and devised a simple dynamometer for recording the power delivered to machinery (see Proceedings, 1858, p. 92).

Mr. Froude became a Member of the Institution in 1852. In 1876 he received the gold medal of the Royal Society for "his researches, both theoretical and experimental, on the Behaviour of Ships, their oscillations, their resistance, and their propulsion." His death, caused by an attack of dysentery, took place on 4th May 1879, at Admiralty House, Simon's Town, Cape of Good Hope, where he had gone on a pleasure trip in H.M.S. *Boadicea* for the benefit of his health.

JAMES HENRY GREAVES was born at Harrogate on 7th June 1846. After serving five years' apprenticeship to Messrs. Thwaites and Carbutt, Bradford, he was employed by that firm for a short time as their representative, and travelled for them on the continent. This position he resigned to undertake an engagement under Dr. Siemens, by whom he was employed for several years in superintending the erection of steel and other works, both in this country and in Russia. In 1877 he was appointed manager of Messrs. Robey & Co.'s establishment at Breslau, and continued in that capacity to the time of his death, which took place at Goerbersdorf, Schlessin, on 9th January 1879, in the thirty-third year of his age. He became a Member of the Institution in 1870.

RALPH DARLING GRUNDY was born at Hindley on 4th October 1846, and was the son of Mr. Robert Grundy, engineer and cotton spinner, of the same place. He served his apprenticeship at Wigan under his uncle, Mr. Peter Johnson; but at the age of nineteen removed to the Wigan Coal and Iron Co.'s Works at Kirkless. Shortly afterwards he went on board Mr. Lancaster's yacht *Deerhound*, and with her went up the Rhine. In 1869 he was made shop-foreman and chief constructor at Kirkless, under Mr. Peter Johnson; in which position he remained until the death of Mr. Thomas Robinson, one of the colliery engineers to the company, when he was chosen to fill the vacant post. This he continued to occupy till 31st December 1878. During this time there were added to the

plant of the Company, under his superintendence as m
engineer, the Alexandra Pit at Haigh, the Sovereign Pi
Leigh, and the two Priestners Pits at West Leigh; re
collectively winding-engine power of 2000 H.P., and c
raising 4000 tons of fuel per day. At the Sovereign
erected a Guibal fan, 40 feet diameter by 15 feet wide, with
case. Underground hauling apparatus was also put down
pits, to the extent of about 40 miles of rope. On the
of Mr. Peter Johnson in January 1879, Mr. Grundy was
to the entire charge of the extensive fitting shop and
department, which post he occupied till his death on 7th
1879, at the age of thirty-three. He was the third of his
engineers, who have died while in the service of the W
and Iron Co. He became a Member of the Institution in 1

William Howe was born at West Auckland, in the
Durham, on 3rd March 1814. He commenced work w
thirteen years of age, and worked at various collieries in t
as a general carpenter until he was twenty-one years of age
then employed for about nine months at the Shildon wor
Stockton and Darlington Railway, as a millwright and patte
In 1835 he went into Lancashire, where he worked as
maker in Messrs. Jones's works at Newton, at the Vulcan
near Warrington, and at Messrs. Mather and Dixon's
Liverpool. In 1840 he removed to Gateshead, and wor
short time with Messrs. Hawks Crawshay and Co.; and i
went to work with Messrs. Robert Stephenson and Co., New
Tyne, as a pattern-maker. In 1842, whilst in their e
perfected the valve-gear known as the link-motion, in
in which it has been almost universally applied to lo
His original sketch and model are now in the South K
Museum. The full history of the invention is give
introduction to Mr. N. P. Burgh's work on Link-M
Expansion Gear, and in Mr. D. K. Clark's work on
Machinery. In 1846 he invented the three-cylinder
engine, a patent for which was taken out in the joint

Mr. George Stephenson and Mr. Howe. In November 1846 he was appointed by Mr. George Stephenson to the post of engineer at the Clay Cross Collieries, and there he remained until his death.

Whilst at Clay Cross Mr. Howe had abundant scope for the development of his mechanical ability, and rarely met with any difficulty which he did not speedily devise some means to overcome. In 1847 he made the first application of the link-motion to a winding engine, using what he called the "twin-solid" form: in which the link was composed of two solid bars, sliding in curved slots on each side of a solid block fixed to the end of the valve-rod. An improved form of this was applied to a large winding-engine erected at Clay Cross in 1854, and has been at work ever since without repair or alteration. In 1864, when designing new winding-engines for an extension of the collieries, he applied a modification of his own of Allan's straight-link motion, with much success. Besides these applications of the link-motion, he designed in 1849 or 1850 a self-acting brake for winding engines; and shortly afterwards the self-acting fence which is now so universally used at the top of colliery winding shafts. About 1867 his health began to fail, but he continued in the discharge of his duties until within a fortnight of his death, which took place on 16th January 1879, in the sixty-fifth year of his age.

Mr. Howe's early education was very imperfect, but after coming to manhood he never ceased in his endeavours to improve it. During the time he was a workman he employed his leisure hours in acquiring mathematical knowledge, and in learning mechanical drawing, in which he soon became very proficient. He was a member of Council of the Chesterfield and North Derbyshire Institute of Engineers (which he largely assisted in promoting), from the time of its formation in April 1871 until his death. He became a Member of this Institution in 1860, and in 1862 gave some particulars of a large Cornish pumping engine, with wrought-iron beam, then in course of erection at Clay Cross. In the following year he contributed a valuable paper fully describing this engine (Proceedings, 1863, p. 248). In 1870, in a discussion on Midland colliery working, he made some remarks on haulage by endless chain at Clay Cross. He

also contributed a paper on an equilibrium slide-valve to the S
Wales Institute of Engineers in 1865, and a paper on the Clay C
blast furnaces to the Chesterfield Institute in October 1872.
was a zealous promoter of the Stephenson Memorial Hall
Chesterfield, and took an active interest in the local business of C
Cross. On 17th April 1872 he was presented with a purse contai
upwards of £200, a handsome gold watch, and an address, "as
acknowledgment for practically developing the invention of the L
motion in August 1842."

WILLIAM EDWARD NEWTON was born in London on 23rd Jan
1818. He was extensively engaged in business as a surveyor
civil engineer. He also acted as a patent agent for a consider
part of his life, and took great interest in the working of
patent laws. He became a Member of the Institution in 18
and in 1873 read a paper on Tilghman's sand-blast pro
(Proceedings 1873, page 260). His death took place on 1st A
1879, at the age of sixty-one.

GEORGE SAXON was born in Manchester on 20th September 1
He was apprenticed with Mr., afterwards Sir William, Fairbair
his Manchester works—an apprenticeship which he completed to
Fairbairn's great satisfaction. Afterwards he superintended
erection of many of Mr. Fairbairn's great engineering works. In 1
he accepted an engagement as foreman to Mr. Benjamin Goodfel
Engineer, at Hyde, near Manchester. While in this employment
1854, he patented a fusible plug for steam boilers, which has pro
highly successful, and is still extensively used. In 1856
commenced business in Openshaw, Manchester, as engineer
millwright—a business which increased considerably under
energetic and skilful management. His great practical knowledge
him to make many improvements in this department of engineer
amongst others an automatic cut-off motion, which is being extensi
applied at the present time. His death took place at his reside
at Openshaw, on 31st October 1879, at the age of fifty-eight.
became a Member of the Institution in 1875.

Institution of Mechanical Engineers.

PROCEEDINGS.

JANUARY 1880.

The THIRTY-THIRD ANNUAL GENERAL MEETING of the Institution was held at the Institution of Civil Engineers, London, on Thursday, 22nd January, 1880, at Three o'clock p.m.; JOHN ROBINSON, Esq., Retiring President, in the chair, succeeded by EDWARD A. COWPER, Esq., President elected at the Meeting.

The Minutes of the last Meeting were read, approved, and signed by the President.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following New Members, Associate, and Graduates were found to be duly elected:—

MEMBERS.

MICHAEL MARY BROPHY,	London.
JOHN DICKINSON,	Sunderland.
JOHN EDWARD EAGER,	Abo, Finland.
ROBERT EDWARDS,	Deal.
JOHN WILFRID DE VILLEMONT GALWEY,	Warrington.
THOMAS HAWTHORN,	Gateshead.
CHARLES HODGSON,	London.
THOMAS BELL LIGHTFOOT,	Newcastle-on-Tyne.
EDWARD RUSSELL MORRIS,	London.
JOHN SAXBY,	London.
JOSEPH WESTWOOD, JUN.,	London.
ROBERT WILSON,	London.
FERDINAND HENRY ZIFFER,	Manchester.

ASSOCIATE.

WASHINGTON BAGSHAWE, . . .	Newcastle-on-Tyne.

GRADUATES.

PERCY BENHAM, ...	London.
RHYS JENKINS, ...	Llanelly.
THE HON. CHARLES ALGERNON PARSONS,	Newcastle-on-Tyne.
JOHN MACKWORTH WOOD, . .	London.

The following Annual Report of the Council was then read :—

ANNUAL REPORT OF COUNCIL.

1880.

The Council have pleasure in laying the following Annual Report before the Meeting, on this occasion of the Thirty-third Anniversary of the Institution.

The roll of the Institution shows that at the end of the year 1879 there were on the list 1178 Members of all classes, as compared with 1140 Members of all classes at the corresponding period of the previous year, giving an effective increase of 38. This increase arises as follows:—there have been elected within the year 86 Members of all classes; there have been lost by deceases 17 Members of all classes, and by resignation or removal from the register 31 Members of all classes.

The following Deceases of Members of the Institution have occurred during the past year:—

CHARLES CAMMELL, ...	Sheffield.
SAMPSON LLOYD FOSTER, ...	London.
WILLIAM FROUDE, ...	Torquay.
JAMES HENRY GREAVES, ...	Breslau.
RALPH DARLING GRUNDY, ...	Wigan.
WILLIAM HOWE, ...	Clay Cross.
WILLIAM EDWARD NEWTON, ...	London.
GEORGE SAXON, ...	Manchester.

The following gentlemen have resigned their Membership in the Institution during the past year :—

Frederick Barker (Associate),	Leeds.
Edward Barton,	Carnforth.
Charles C. Beardshaw,	Sheffield.
Charles Bell,	Taganrog.
Francis Berry,	Sowerby Bridge.
Isaac Bradley,	Connecticut.
Henry Cochrane,	Middlesbrough.
William Langton Coke,	Alfreton.
Willoughby Crampton,	Sheffield.
Frank Evers,	Stourbridge.
John Fairless,	Newcastle-on-Tyne.
John Gibson,	Sunderland.
Henry Hind,	Nottingham.
Samuel Jackson,	Sheffield.
Alexander Frederick Jones (Graduate),	Folkestone.
William Jones,	Manchester.
Edward Rigge Lloyd,	Birmingham.
Horace Mayhew (Graduate),	Wigan.
William Hall Pearson,	Birmingham.
Daniel Pidgeon,	London.
Joseph de Rosthorn,	Vienna.
Arthur Sparrow,	Longton.
John Stevenson,	Middlesbrough.
William Weldon Symington,	Market Harborough.
William Walker,	Saltburn.
Stuart Crawford Wardell,	Alfreton.
William Wright,	Lostwithiel.

The following gentlemen have ceased to be Members of the Institution during the past year :—

Frederick Ayton,	Glasgow.
John Cochrane,	London.
Thomas Deakin,	Natal.
James Durie,	Manchester.
John Hartness,	Sunderland.
Benjamin Carr Lawton (Associate),	Corbridge.
Augustus Stephen Lukin,	Chesterfield.
Thomas Edward Day Plum,	London.

JOSEPH STEPHENSON (Graduate), ...	Tunstall.
HENRY JOSEPH WEST, ...	London.
CHARLES FREDERIC TRELAWNY YOUNG, ...	London.

The accounts for the past year, having been passed by the Finance Committee, and having been audited by Messrs. Robert A. McLean & Co., Public Accountants, are now submitted to the Members (*see Appendix I.*). It will be seen that the receipts for the year have been £3782 13*s*. 3*d*., while the expenditure for the year has been £3674 5*s*. 5*d*., showing a balance of receipts over expenditure of £108 7*s*. 10*d*.

A Balance Sheet is also given, showing the financial position of the Institution at the end of the year. From this it will be seen that the total investments and other assets amounted to £12,862 3*s*. 2*d*., and the total liabilities to £589 10*s*. 7*d*.; leaving the capital of the Institution at the end of the year at £12,272 12*s*. 7*d*.

The greater portion of the capital of the Institution is invested, as will be seen, in Four per cent. Railway Debenture Stocks, registered in the name of the Institution: the former Trustees having formally transferred them to the Institution, in accordance with the resolution passed at the last Annual General Meeting.

At the last Annual General Meeting a sum of £300 was voted by the Institution for the purposes of Experimental Research on mechanical questions. The Council, after full consideration, decided that the subjects to be first investigated should be the following:—the Hardening, Tempering, and Annealing of Steel; the Best Form of Riveted Joints to resist strain, in iron or steel, or in combination; and Friction between solid bodies at High Velocities. Committees were appointed to deal with each of these three subjects, on which many gentlemen of scientific eminence consented to act. In accordance with the instructions of the Council, each Committee made it their first duty to collect and collate all the information already available upon that particular subject. This, as was expected, proved to be a work of much time and labour; but it was at length so far completed that each Committee was able to present to the

Council a First Report, stating the result of their investigation into the subject, and the nature of the experiments which in their opinion it was still desirable to make upon it. These Reports have been approved, and circulated among the Members; and the Council feel sure that they are only representing the wishes of the Institution in proposing a special vote of thanks to the Members of the three Committees, and especially to the Honorary Reporters, Mr. Wm. Anderson, Professor W. C. Unwin, and Professor A. B. W. Kennedy, for the great amount of time and labour they have given, and for the great scientific skill evinced in the production of these Reports.

The following Donations to the Library of the Institution have been received during the past year, for which the Council have the pleasure of expressing their thanks to the Donors. Feeling the great desirability of enlarging and improving the Library, which they hope to render still more available for the purposes of the Institution, the Council again invite the Members to make donations of books, original pamphlets, or reports.

(*For List of Donations see Appendix II.*)

In the course of 1879 the Meetings held were the Annual General Meeting, an April Meeting, and a June Meeting, all in London, the Summer Meeting in Glasgow, and the Autumn Meeting in Manchester: thus making five Meetings in the year, instead of four as heretofore. Ten days in all were devoted to the reading and discussion of Papers, being three more than in any previous year. The list of Papers is as follows:—

On the Construction of Armour to resist Shot and Shell; by Capt. C. O. Browne, R.A.

The Heslop Engine, a chapter in the history of the Steam Engine; by Mr. H. A. Fletcher.

On the Economy of Railway Working; by Mr. R. Price Williams.

On recent Brake Experiments upon the Lyons Railway; by M. George Marié.

On the Effect of Brakes upon Railway Trains; by Captain Douglas Galton, C.B., Hon. D.C.L., F.R.S. (Third Paper.)

On the Construction and Comparative Merits of the Safety Lamps generally in use; by Mr. Alan C. Bagot.

On Electric Lighting; by Dr. John Hopkinson, F.R.S. (First Paper.)

Experiments referring to the use of Iron and Steel in High-Pressure Boilers; by Mr. David Greig and Mr. Max Eyth.

On the Compounding of Locomotive Engines; by M. Anatole Mallet.

On Injector Hydrants for Fire Extinction; by Mr. J. H. Greathead.

On the Pneumatic Marine Governor; by Mr. D. J. Dunlop.

On the Velometer Governor for Marine and Stationary Engines; by Mr. F. W. Durham.

On the Maintenance of Constant Pressure in Water Service Pipes; by Mr. Stephen Alley.

On Barton and West's Water Pressure Reducer; by Mr. W. H. Thomas.

On Barton and West's Piston Water Meter; by Mr. W. H. Thomas.

On the Flow of Water round River Bends; by Professor James Thomson, F.R.S.

On the Forging of Crank Shafts; by Mr. W. L. E. McLean.

On Water-Power Engines with Variable Stroke; by Mr. John Hastie.

On the Working of Traction Engines in India; by Mr. R. E. B. Crompton.

On the Construction and Working of a Vertical-Action Steam-Dredger in India; by Mr. R. B. Buckley.

On the Loss of Power in the Screw Propeller, and the means of improving its Efficiency; by the Hon. R. C. Parsons.

On Fireless Locomotives for Tramways; by M. Léon Francq.

The attendances at the Meetings were—at the Annual General Meeting 62 members and 27 visitors; at the April Meeting 83 members and 73 visitors; at the June Meeting 71 members and 39 visitors; at the Summer Meeting 175 members and 143 visitors; at the Autumn Meeting 50 members and 32 visitors. At the April Meeting the experiment was tried of changing the hour of meeting from the morning to the evening, and the consequent improvement in the attendance was very marked.

The Summer Meeting was held in Glasgow, and despite the severe depression of trade proved thoroughly successful and enjoyable. The works of the City and district were freely thrown open to the Institution, and several special excursions were organised, at which the Members were hospitably entertained. The Meeting was brought to a close by an excursion in the steamer *Iona*, through the Kyles of Bute and up Loch Fyne to Inverary, on the kind invitation of the Institution of Engineers and Shipbuilders in Scotland.

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council in rotation, go out of office this day. The result of the ballot for the Council of the year 1880–81 will be reported to the present Meeting.

APPENDIX I.

Dr. ACCOUNT OF EXPENDITURE AND RECEIP

Expenditure.				£	s.
To Printing and Engraving Proceedings	1053	8	0		
Less Authors'. Copies of Papers, repaid	92	0	6	961	7
,, Stationery, Binding, and General Printing				227	5
,, Rent				550	0
,, Salaries and Wages				1202	16
,, Coals, Firewood, and Gas				29	5
,, Fittings and Repairs				39	12
,, Office Furniture				49	5
,, Postages.				222	3
,, Insurance, 2 years				6	6
,, Law Charges				12	12
,, Travelling Expenses				19	13
,, Petty Expenses				57	2
,, Meeting Expenses—					
Printing	47	1	0		
Reporting	77	8	8		
Diagrams, Screen, &c.	32	16	0		
Travelling and Incidental Expenses	70	7	2	227	12
,, Research				69	1
,, Balance, being excess of Receipts over Expenditure				108	7
				£3,782	13

Dr. BALANCE SHEE

	£	s.
To Cash due to Bank, for cheques issued but not presented . .	589	10
Capital of the Institution at this date	12,272	12
	£12,862	3

(*Signed*) EDWARD A. COWPER, EDWARD EASTON } *Finance Committee.*

APPENDIX I.

FOR THE YEAR ENDING 31ST DECEMBER 1879. *Cr.*

Receipts.				£	s.	d.
By Entrance Fees—						
71 *New Members at £2*	142	0	0			
1 „ *Associate* „ £2	2	0	0			
13 „ *Graduates* „ £1	13	0	0			
3 *Graduates transferred to Members at £1*	3	0	0	160	0	0
„ Subscriptions for 1879—						
967 *Members at £3*	2,901	0	0			
22 *Associates* „ £3	66	0	0			
49 *Graduates* „ £2	98	0	0			
3 *Graduates transferred to Members at £1*	3	0	0	3,068	0	0
„ Subscriptions in arrear—						
23 *Members at £3*	69	0	0			
1 *Graduate at £2*	2	0	0	71	0	0
„ Subscriptions in advance—						
19 *Members at £3*	57	0	0			
1 *Graduate at £2*	2	0	0	59	0	0
„ Interest—						
From Bank	7	4	7			
„ *Investments*	351	12	8	358	17	3
„ Reports of Proceedings—						
Extra Copies sold				65	16	0
				£3,782	13	3

AS AT 31ST DECEMBER 1879. *Cr.*

				£	s.	d.
By Cash—*In Bank*	175	18	3			
„ *Secretary's hands*	250	0	0	425	18	3
„ Investments—						
£3,178 *London & N. W. Ry. 4% Debenture Stock*						
£2,200 *North Eastern* „ „ „ „						
£1,800 *Midland* „ „ „ „						
£1,800 *Great Western* „ „ „ „						
£8,978			*cost*	8,868	4	11
„ Subscriptions in Arrear				318	0	0
„ Office Furniture and Fittings				350	0	0
„ Library and Proceedings				2,500	0	0
„ Drawings, Engravings, Models, Specimens, and Sculpture				400	0	0
				£12,862	3	2

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APPENDIX II.

LIST OF DONATIONS TO THE LIBRARY.

On the Acquisition of Railways by the State, and on Railway Facts, by F. T. Haggard; from the author.

On Fuel, its Combustion and Economy, by D. K. Clark; from the author.

On Accidents in Mines, by Alan Bagot; from the author.

On Experimental Firing at Shields of 55 Centimetres, at Spezia; from Captain English.

On the Steam Engine of the Future, by John Bourne; from the author.

Charts of Prices of Iron and Coal for successive years, by Walter E. Wood; from the author.

A Treatise on the Locomotive Engine, by C. Pambour; from Mr. Bryan Donkin, Jun.

L'Industrie de la Papeterie, by G. Planch; from Mr. Bryan Donkin, Jun.

On a Swedish Calculating Machine, by G. and E. Schentz; from Mr. Bryan Donkin, Jun.

Mechanics, by W. Whewell; from Mr. Bryan Donkin, Jun.

On Canal Navigation, by W. Fairbairn; from Mr. Bryan Donkin, Jun.

On the Steam Engine, by J. Milne; from Mr. Bryan Donkin, Jun.

On the Steam Engine, by J. Farey; from Mr. Bryan Donkin, Jun.

Nautical Experiments, by Colonel Beaufoy; from Mr. Bryan Donkin, Jun.

Various Nos. of the Philosophical Magazine, Vols. I.–XI.; from Mr. Bryan Donkin, Jun.

Installation du Service d'Eaux Municipal de Nijni-Novgorod, by L. Poillon; from the author.

On Railway Appliances, by J. Wolfe Barry; from the author.

On Friction, by R. H. Thurston; from Mr. V. Pendred.

Étude comparée des Régulateurs, by G. Marié; from the author.

Revue Industrielle, 1874–78; from Mr. Henry Chapman.

Annales Industrielles, vols. 1 and 2; from Mr. Henry Chapman.

Traité de Métallurgie, by M. Jullien; from Mr. Henry Chapman.

Recherches sur la Composition des Aciers, by M. Jullien; from Mr. Henry Chapman.

Spon's Dictionary of Engineering; from Mr. J. S. Hopkins.

Travaux Publics des États-Unis d'Amérique en 1870, by M. Malézieux; from Mr. J. S. Hopkins.

Essential Elements of Practical Mechanics, by Oliver Byrne; from Mr. J. S. Hopkins.

Practical Illustrations of Land and Marine Engines and Boilers, by N. P. Burgh; from Mr. J. S. Hopkins.

The Mechanician and Constructor for Engineers, by Cameron Knight; from Mr. J. S. Hopkins.

On Electric Lighting and its Practical Application, by J. N. Shoolbred; from the author.

Étude comparative sur le Pouvoir Éclairant du Gaz et de l'Électricité, by E. Cose; from the Gas Association of France.

On the Working of Punkahs in India, by the Hon. R. C. Parsons; from the author.

On the Transmission of Vocal and other Sounds by Wire, by W. J. Millar; from the author.

Note sur la Résistance des Tubes, by Théodore Belpaire; from the author.

On the Sanders and Bolitho Continuous Automatic Brake; from Mr. R. D. Sanders.

Pompes de l'Exposition à Paris, by L. Poillon; from the author.

On the London Water Supply, by a Civil Engineer; from Mr. Hyde Clarke.

On the Water Supply of the Metropolis, by W. Burch; from Mr. Hyde Clarke.

On Sewer Gas and its Effects (extracts); from Mr. Hyde Clarke.

Report on the Berdan Machine, by T. H. Henry, F.R.S., and J. S. Atkinson; from Mr. Hyde Clarke.

Abhandlungen der Königlichen Akademie der Wissenschaften, Berlin; from Mr. Hyde Clarke.

Mittheilungen des Gewerbe-vereins, 1876, part 6; from Mr. Hyde Clarke.

Notes on some Statical Problems connected with Mechanics, by Professor Kennedy; from the author.

On the Treatment of Steel Plates, by Mr. H. Sharp; from the author.

On the Sea-Ports of France, with plates; from the Minister of Public Works.

List of Lighthouses &c. in the Chinese Section, 1879; from the Secretary of the Chinese Customs Office.

Conference on Continuous Brakes; from M. D. Banderali.

Aeneidea, by James Henry; from Mr. Thomas E. Henry.

On Improvements in Sulphuric Acid Manufacture, by W. G. Strype; from the author.

American Engineering, as illustrated by the American Society of Civil Engineers at the Paris Exhibition, 1878; from Mr. Edward P. North.

Report upon Brakes used on the Lyons Railway, by M. Marié; from the author.

Esperienze sulla Resistenza dei principali Metalli dei Bocche da Fuoco, by G. Rosset; from the Reale Accademia dei Lincei, Rome.

On Electricity and Magnetism, by Professor Jenkin; from the author.

On Iron and Steel for Constructive Purposes, by Daniel Adamson; from the author.

On Riveting, by M. Ludewig; from Dr. Ermenyi.

On Differential Brakes, by M. Pechan; from Dr. Ermenyi.

Étude sur l'Exploitation des Chemins de Fer par l'État, by F. Jacqmin; from Mr. Henry Chapman.

La Locomotive sans Foyer, by Léon Francq; from the author.

On the Strength and Elasticity of Materials, by W. J. Millar; from the author.

On Steam Ship Efficiency, by Robert Mansel; from the author.

Index to our Railway System and our Leading Lines (third vol.), by William Fleming; from the author.

Transmission des Forces Motrices, by A. Achard; from the author.

Advantages of Wind, Water, and Steam, by Samuel B. Goslin; from Messrs. J. Warner and Sons.

Études sur le Blanchissage du Linge, by N. Sergueeff; from the author.

Annual Report, Public Free Library, Manchester.

Annual Report, Public Free Library, Liverpool.

Petition for Prolongation of Patent on Steel; from Sir Joseph Whitworth.

Our Railways, should they be Private or National Property? by E. J. Watherston; from the author.

On the Latest Improvements in Marine Engines and Boilers, by J. R. Ravenhill; from the author.

On the Record of Train Mileage and Engine Duty on Indian Railways, by C. E. Cardew; from the author.

Report on Russian Railways; from Mr. T. Urquhart.

On the Structure of Cast-Steel Ingots, by D. Chernoff; from Mr. William Anderson.

Reports of the Academy of Sciences, France; from the Academy.

Reports of the Royal Academy of Sciences, Belgium; from the Academy.

Reports of the Royal Institute of Engineers, Holland; from the Institute.

Annals of the École des Ponts et Chaussées, Paris; from the Directors.

Annals of the Conservatoire des Arts et Métiers, Paris; from the Directors.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Journal of the French Society for the Encouragement of National Industry; from the Society.

Journal of the Marseilles Scientific and Industrial Society; from the Society.

Proceedings of the Engineers' and Architects' Society of Trieste; from the Society.

Proceedings of the Engineers' and Architects' Society of Milan; from the Society.

Proceedings of the Engineers' and Architects' Society of Florence; from the Society.

Proceedings of the Engineers' and Architects' Society of Canton Vaud; from the Society.

Proceedings of the Engineers' and Architects' Society of Austria; from the Society.

Proceedings of the Engineers' and Architects' Society of Hanover; from the Society.

Proceedings of the Engineers' and Architects' Society of Prague; from the Society.

Proceedings of the Industrial Society of St. Quentin; from the Society.

Proceedings of the Industrial Society of Mulhouse; from the Society.

Proceedings of the Industrial Society of the North of France; from the Society.

Proceedings of the Saxon Society of Engineers; from the Society.

Proceedings of the Swedish Society of Engineers; from the Society.

Journal of the Norwegian Polytechnic Society; from the Society.

Journal of the Franklin Institute; from the Institute.

Transactions of the American Society of Civil Engineers; from the Society.

Transactions of the American Institute of Mining Engineers; from the Institute.

Report of the Smithsonian Institution; from the Institution.

Proceedings of the Engineers' Club of Philadelphia; from the Club.

Proceedings and Journal of the Asiatic Society of Bengal; from the Society.

Report of the Sassoon Mechanics' Institute, Bombay; from the Institute.

Proceedings of the Institution of Civil Engineers; from the Institution.

Journal of the Iron and Steel Institute; from the Institute.

Transactions of the Society of Engineers; from the Society.

Transactions of the Institution of Civil Engineers of Ireland; from the Institution.

Transactions of the North of England Institute of Mining and Mechanical Engineers; from the Institute.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Transactions of the Institution of Engineers and Shipbuilders in Scotland; from the Institution.

Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers; from the Institute.

Proceedings of the Cleveland Institution of Engineers; from the Institution.

Proceedings of the Chesterfield and Derbyshire Institution of Engineers; from the Institution.

Proceedings of the Royal Society of London; from the Society.

Proceedings of the Royal Society of Edinburgh; from the Society.

Proceedings of the Royal Institution; from the Institution.

Transactions of the Institution of Surveyors; from the Institution.

Proceedings of the Association of Municipal and Sanitary Engineers and Surveyors; from the Association.

Journal of the Royal United Service Institution; from the Institution.

Papers of the Royal Engineer Institute; from the Institute.

Lecture at the School of Military Engineering, Chatham; from the School.
Proceedings of the Royal Artillery Institution; from the Institution.
Journal of the Royal Agricultural Society of England; from the Society.
Journal of the Statistical Society; from the Society.
Report of the British Association for the Advancement of Science; from Association.
Journal of the Scientific Association of France; from the Association.
Proceedings of the Scientific and Mechanical Society of Manchester; from Society.
Report of the Royal Cornwall Polytechnic Society; from the Society.
Report of the Miners' Association of Cornwall and Devon; from the Associ
Transactions of the Institution of Naval Architects; from the Institution.
Transactions of the Royal Institute of British Architects; from the Institut
Reports of the British Association of Gas Managers; from the Association.
Report of the Manchester Geological Society; from the Society.
Journal of the Royal Scottish Society of Arts; from the Society.
Proceedings of the Philosophical Society of Glasgow; from the Society.
Journal of the Liverpool Polytechnic Society; from the Society.
Journal of the Society of Arts; from the Society.
Report of the Manchester Steam Users' Association; from Mr. Lavingto Fletcher.
Report of the Boiler Insurance and Steam Power Company; from the Comp
Revue Générale des Chemins de Fer; from the Directors.

The Engineer; from the Editor.
Engineering; from the Editor.
Iron; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.
The Colliery Guardian; from the Editor.
The Iron and Coal Trades Review; from the Editor.
The Railroad Gazette; from the Editor.
The Engineering and Mining Journal; from the Editor.
The Inventor's Record and Industrial Guardian; from the Editor.
The Universal Engineer; from the Editor.
The Marine Engineer; from the Editor.
The Contract Journal; from the Editor.
The Machinery Market; from the Editor.

The President wished to call special attention to the paragraph in the Report referring to the thanks due to the members of the Research Committee, and especially to the reporters. All who had seen the reports would well understand how much labour had been performed, and how much care had been bestowed upon them by the committees, and especially by the reporters. He would therefore ask the members to express their thanks to those gentlemen by acclamation.

The vote of thanks was passed by acclamation.

The President said that the next point in the Report to which he wished to refer was the increased number of meetings, and the larger number of papers read during the year. This, joined with the expense of the Research Committee, had involved an increased expenditure, and, in consequence, the balance of receipts over expenditure was very small for the past year. It was therefore to be hoped that every member of the Institution would do his best to increase the number of members, so as to afford the means of pursuing Research (a very important part of the work of the Institution), and also of increasing their number of papers, without feeling that they were always on the limit of their means of expenditure. He would now put the adoption of the Report to the meeting.

The motion was carried unanimously.

Mr. Daniel Adamson would like to call to the remembrance of the meeting the character of the late Mr. William Howe, whose name had been read among the deceased members of the Institution. He had known Mr. Howe personally when he was a pattern-maker on the oldest railway in the country—the Stockton and Darlington,—and before he gave to the world the reversing link, now almost the universal mode of manipulating the locomotive engine throughout the civilised world. In him the Institution had lost a most industrious man, a very careful thinker, and a sound practical mechanic. At the request of the President, he would not now attempt to describe his career, but should be pleased to contribute a short account for publication amongst the other memoirs in the Proceedings of the Institution.

The PRESIDENT announced that the Ballot Lists for the ele of Officers had been opened by a committee of the Council, and following members of Council were found to be elected for present year:—

PRESIDENT.

EDWARD A. COWPER, . . . London.

VICE-PRESIDENTS.

JEREMIAH HEAD, ... Middlesbrough.
PERCY G. B. WESTMACOTT, . Newcastle-on-Tyne.

MEMBERS OF COUNCIL.

DANIEL ADAMSON, ... Manchester.
EDWARD EASTON, . . . London.
J. HAWTHORN KITSON, . . . Leeds.
WILLIAM MENELAUS, . . . Dowlais.
JOSEPH TOMLINSON, JUN., . . London.
R. PRICE WILLIAMS, . . . London.

The Council for the present year would therefore be follows:—

PRESIDENT.

EDWARD A. COWPER, . . . London.

PAST-PRESIDENTS.

SIR WILLIAM G. ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., . . . Newcastle-on-Tyne.
FREDERICK J. BRAMWELL, F.R.S., London.
THOMAS HAWKSLEY, F.R.S., . . London.
JAMES KENNEDY, . . . Liverpool.
JOHN RAMSBOTTOM, . . . Alderley Edge.
JOHN ROBINSON, . . . Manchester.
C. WILLIAM SIEMENS, D.C.L., F.R.S., London.
SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., . . . Manchester.

VICE-PRESIDENTS.

I. LOWTHIAN BELL, M.P., F.R.S.,	Northallerton.
CHARLES COCHRANE,	Stourbridge.
JEREMIAH HEAD,	Middlesbrough.
CHARLES P. STEWART,	Sunninghill.
FRANCIS W. WEBB,	Crewe.
PERCY G. B. WESTMACOTT,	Newcastle-on-Tyne.

COUNCIL.

DANIEL ADAMSON,	Manchester.
WILLIAM ANDERSON,	London.
HENRY CHAPMAN,	London.
THOMAS R. CRAMPTON,	London.
EDWARD EASTON,	London.
DAVID GREIG,	Leeds.
THOMAS R. HETHERINGTON,	Manchester.
J. HAWTHORN KITSON,	Leeds.
WILLIAM MENELAUS,	Dowlais.
ARTHUR PAGET,	Loughborough.
JOHN PENN,	London.
GEORGE B. RENNIE,	London.
WILLIAM RICHARDSON,	Oldham.
JOSEPH TOMLINSON, JUN.,	London.
R. PRICE WILLIAMS,	London.

The PRESIDENT said that, whether he was guilty of an irregularity or not in doing what he now proposed, he could not vacate the chair, and ask his friend Mr. Cowper to occupy it, without saying a few words in expression of gratitude for the way in which he had been treated by the Council, by the Members, and by the officers, during his two years of office. They had passed through rather turbulent times, not turbulent at all in the sense of disputes and quarrelling, but there had been a great many alterations in the regulations and in the position of the Institution during his presidency; and during that time he had not had a single difficulty arising to himself

personally, from the action of any member of the Council, or of member or any officer of the Institution. He desired there heartily to express to each of them his thanks for the way in w he had been treated during his occupation of the chair. He w now ask Mr. Cowper, who was better known to many of the mem of the Institution than himself, to take the vacant chair.

The chair was then taken by Mr. E. A. Cowper.

Mr. A. Paget said that, at the request of the newly-elected Presi of the Institution,—and he was sure he might say on behalf of ev one present also,—he begged to propose an earnest and sincere of thanks to the retiring President, Mr. Robinson. (Applause.) was quite unnecessary to waste their time by many words, for mere mention of what he had to propose had already elicited expression of approval from all present, which he knew would straight to Mr. Robinson's heart. They must all have felt, w that gentleman was in the chair at their meetings, what an admir President he had made. When help or support of any kind had t given, it had been given with all heartiness, and as if it came from man himself; and when he had to call any of them to order, they all felt that it was the President doing it, and that he was right they were wrong. With regard to the work of the Council, they to make, in consequence of their desire to consolidate their posi in London, a great many changes; and a great deal of care had required to work correctly under the new system, as an incorpor Institution. He wished he could convey to the Members the st belief which he entertained, and which he knew the whole Cou also entertained, that any success they had had in that direc had been due, first to Mr. Robinson's extensive experience, and to the way in which he had thrown himself heart and soul into work. Nothing had been too great for him, and nothing had too small. He therefore asked the members to pass a hearty vot thanks to Mr. Robinson for his two years' labour; and he might a hope, that it would be followed by many years of further la as Past-President.

The PRESIDENT said he took it for granted that the motion was seconded by every member present, and he would at once put it to the meeting.

The motion was carried by acclamation.

Mr. ROBINSON said he had scarcely words to say how much he felt the manner in which Mr. Paget had been good enough to propose the thanks of the Institution for the services he had been able to render during the time of his presidency. He felt that he had been only the executive instrument of the Council and of the Members of the Institution, in doing a large amount of the work which had been done during the past two years; and as far as he was personally concerned, he considered himself to have been very happy in occupying the chair of the Institution when so much had been done which, as he hoped, augured well for its future usefulness. He had to thank Mr. Paget, the President, and the Members generally, for the way in which the resolution had been proposed and accepted. He hoped they might still live and labour together, and, when better times came upon them, might see the Institution growing still more rapidly than it had grown in the past two years.

The PRESIDENT then delivered the following inaugural Address:—

ADDRESS OF THE PRESIDENT.

GENTLEMEN,—

Having had the honour thirty-three years ago of assisting in the formation of the Institution of Mechanical Engineers, I now have the pleasure of thanking you very cordially for your confidence in entrusting me with still greater responsibility in the conduct of the affairs of the Institution. I must tell you honestly that the position in which you have so kindly placed me to-day is not one that I have ever coveted or sought for, as I consider so much responsibility attaches to it; but if by hard work and close attention to the various interests of the Institution I am able so to assist in its conduct as to give you satisfaction, I shall feel amply repaid, and shall not spare myself any pains that may be necessary to accomplish the object. But one thing I must ask of you—and without it I should only expect to fail—and that is your kind and decided support of the chair at all our meetings, together with such indulgence to the occupant for the time being, as you have always exercised to our late President, than whom we have never had a more genial and truly admirable leader to conduct us forward in the paths of science and practice.

One matter I may allude to, as sufficient time has now elapsed to show the wisdom of the important step that was taken at the time. I need hardly say I refer to the transplanting of the Institution to London. This has proved a perfect success: because the metropolis is now the true centre of England, and the headquarters of the Mechanical Engineering of the kingdom. The number of our Members has greatly increased, the quality and interest of our Papers has improved, and the attendances at our Meetings are more numerous. I long foresaw that this removal was only a question of time, as soon as the present lines of railway had express trains direct to the

metropolis, not only without stopping at Birmingham, but without going within fifteen miles of it. The Institution now so completely stands at the head of Mechanical Engineering in this country, and is so fully admitted by all other institutions to occupy that proud position, that it is but natural that it should rest in the metropolis, as its fit and proper home; and long may it pursue its peaceful and thoroughly useful course. The Institution, having from the first been conducted with a due regard to economy, has never been in debt; and the result is that it is now comfortably and conveniently settled in excellent offices, well suited for its requirements for many years to come: this is the more satisfactory, as it is most difficult to find a good site for such an Institution in Westminster.

I do not propose to-day to trouble you with anything like a history or résumé of Mechanical Engineering, as that has been done much better than I could hope to give it; but, if not trying your patience too much, I should wish to say a few words, direct to the point, with regard to the position of this country among the nations, in respect to the advancement of manufactures generally. Now it cannot be doubted for a moment but that the manufactures and commerce of this country depend very greatly upon engineering skill and invention; and if England is to continue to be called "the manufactory of the world," we must on no account shut our eyes to what is now going on around us in many countries. I much fear that some of our manufacturers have so little enterprise about them that they consider they are doing enough if they *make* things—perhaps chiefly or entirely by hand—as their fathers did, in small numbers: instead of attempting to *manufacture* articles in a better manner, in large numbers, by machinery. They seem to forget that in past times the demand for their goods depended very much upon the fact that they had no rivals or competitors for the trade: at that time foreigners had not devoted themselves to manufactures, and indeed had been much hindered from so doing by the very frequent occurrence of wars actually within their countries: whereas we have had no wars in this country for two hundred years or more. Now there is one important fact, that has perhaps hardly been considered sufficiently by mechanical engineers and manufacturers generally, and it is this:—

when railways first began to spread over the continent, engineeri tools and machines were just springing into existence in Englar and partly for the purpose of manufacturing locomotives, for whi there was a large demand. Then, when foreigners had to rep their engines, they bought engineering tools and machines, and we able to work them without any very highly skilled labour, such as o old millwrights were obliged to possess in our fathers' and grandfathe time: so that in a very short time, despite the want of skilled labou the continental firms became not only the manufacturers of the own locomotives, but of all other kinds of machinery. Hen if our commerce is to flourish and our manufacturers are to ke to the front, then, instead of trying to avoid adopting any ne improvements, and refusing to experiment or to incur any outlay f the purpose of improving their wares and the means of produci them, they should work heartily—and Mechanical Engineers shou do so too—in adopting and improving machinery to produce in better manner, by power, in quantity, and therefore economicall what had previously been *made* in a small way, expensively, by han Often, too often, a good thing is allowed to lie dormant for yea because each manufacturer thinks he will let some one else in t trade spend his money to try the proposal; but the energy shown the United States (and on the continent also very often), in provi a new thing as soon as brought out, and adopting it if good, has wonderful effect in promoting progress and increasing the prosperi of the country. Sometimes it has struck me that Mechanic Engineers hardly seem to think it their province to strive to impro manufactures generally, and that they confine their attention t much to tools and engines, more particularly for engineeri purposes: whereas a little more, or I would say a great deal mo co-operation, between manufacturers who know what is wanted a engineers who would quickly find out how to accomplish it, wou be of the greatest possible advantage to the commerce a manufactures of the country.

A difficulty well stated is half *overcome* already.

But our manufacturers and mechanical engineers must com together, must interchange their ideas, and correspond freely, if an

great good is to be accomplished, in maintaining this country in the proud position of being the manufactory of the world; and as some of us gave an earnest helping hand to establish this Institution, so I would venture to ask all our Members to join hands with our friends the manufacturers, to make as much use as possible of the advantages of this Institution, which, as stated in our rules, was established "to "enable Mechanical Engineers to meet and to correspond, and to "facilitate the interchange of ideas respecting improvements in the "various branches of mechanical science, and the publication and "communication of information on such subjects."

The PRESIDENT said that, in accordance with notice given at the last meeting, he had to move the adoption of the following additional Bye-Law:—

A Graduate or Associate desirous of being transferred to the class of Members shall forward to the Secretary a recommendation according to Form E in the Appendix, signed by not less than five Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the candidate according to Form F if an Associate, and according to Form G if a Graduate; but his name shall not be added to the list of Members until he shall have signed the Form H, and, if a Graduate, shall have paid £1 additional entrance fee, and £1 additional subscription for the current year.

FORM E.

MR. being of the required age, and desirous of being transferred into the class of Members of the Institution, we, the undersigned, from our personal knowledge, recommend him as a proper person to become a Member of the Institution of Mechanical Engineers.

FORM F.

SIR,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature. If this be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient Servant,

Secretary.

FORM G.

SIR,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature, and until your additional Entrance Fee (£1) and additional Annual Subscription (£1) be paid for the current year. If these be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient Servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of Members of the Institution of Mechanical Engineers, do hereby agree, that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the meetings thereof as often as I conveniently can; provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

The motion was carried unanimously.

The PRESIDENT said that notice had been given of two motions by Mr. E. J. C. Welch. He did not know whether that gentleman was present, or any one else on his behalf.

Mr. JEREMIAH HEAD said, if no one was present who had been especially entrusted by Mr. Welch with the moving of the Bye-laws of which he had given notice, he begged leave to do so; not that he wished to commit himself to any approval of them in any form, but simply in order that they might be fully discussed and disposed of. He would therefore move them without note or comment, as follows:—

(1.) "Any Member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers, complete with their diagrams, shall then be forwarded to him at least fourteen clear days prior to the date of the meeting at which they are intended to be read; and every Paper with regard to which this has not been done shall not be read at such meeting, if any Member who should have received a copy of the same objects thereto."

(2.) "At any meeting of the Institution Members shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding meeting."

Mr. A. PAGET said, as no one else seconded the motions, he would do so for the sake of getting them discussed. He desired to guard himself by saying that, as the motions now stood, he should be very sorry to see them adopted; but, with the view of amendments being proposed, he ventured to second them.

Mr. ROBINSON said that on behalf of the Council he had to move amendments to the motions proposed in Mr. Welch's name. With regard to the first, it would be manifestly impossible for the Council to supply every member fourteen days before a meeting with copies of the papers and diagrams, inasmuch as it often happened that the paper itself was not printed by that time, much less were the diagrams completed or engraved. The Council were disposed to think that the first of the two motions should stand thus:—

"Any Member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be

forwarded to him as early as possible prior to the date of the meeting at which they are intended to be read."

Mr. T. R. CRAMPTON seconded the amendment.

Mr. D. ADAMSON had great respect for the judgment of Mr. Welch generally, but thought he had been most unfortunate in bringing forward a proposition to alter rules that had worked very well. If Mr. Welch and those who thought with him would get their papers ready three months or so before they were required, then those papers could be sent out to all the members without difficulty, and without the necessity of any new rule. But the papers read before the Institution should be anxiously and carefully written, and sometimes they could only be got ready a short time before they were wanted. Some critics indeed might desire to have the opportunity of consulting mechanical dictionaries and all the old literature on the subject, and then to parade their borrowed light at the meeting; but that would be a very unfortunate state of things. The papers of the Institution were written to bring before the members the current out-door practice, and the science of the workshop and the laboratory, and not what had been gathered out of books. Hence they ought not to throw any obstacles in the way of those who desired to give them information, but should let them bring it forward as soon and as heartily as they could; and for those who were not in a position to discuss it, the wisest plan would be to hold their tongues. He therefore invited the members not to pass either the original motion or the amendment, which only tinkered with bye-laws or rules that did not require to be touched.

Mr. CHARLES COCHRANE thought Mr. Adamson had not looked at the harmless character of the amendment, which did but carry out formally what had been the practice for some time past, and authorise the Secretary to do that which he was in the habit of doing, but which was perhaps informal without such authority. By this amendment any member, on giving notice, might receive a copy of the papers as early as possible prior to the meeting. All that Mr. Adamson had said was strictly applicable to the resolution originally proposed by

[redacted]

Mr. Welch, and this he fully endorsed; but in the shape in which the motion had been amended, he thought it worth while to consider it, and to pass it.

Mr. R. H. TWEDDELL wished to support the observations of Mr. Adamson. If the resolutions, even as amended, were harmless, there was no advantage in encumbering the bye-laws with them.

Mr. W. W. HULSE said if the Council could send to any member, on giving notice beforehand, the printed matter to be read at the meetings, he did not see why they could not send it to all members, and then no notice would be required. He agreed with Mr. Adamson in thinking that the proposal was superfluous, and an unnecessary tinkering with the bye-laws.

The PRESIDENT desired to offer a few words of explanation. It had been the practice for a long time past to send copies of the papers to any gentleman who sent his name in beforehand; and the proposal was merely to render legal by resolution what had been done by the Council for some time already; and to provide that, if a member asked for the papers for the whole year, he should receive them.

The amendment was then put and carried.

Mr. ROBINSON proposed on behalf of the Council the following amended form of the second resolution moved on behalf of Mr. Welch:—"At any meeting of the Institution any Member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding meeting, provided that he signifies his intention to the Secretary at least one month previously to the meeting, and that the Council decide to include it in the notice of the meeting, as part of the business to be transacted." It was only fair to any gentleman who had read a paper at a preceding meeting, that, if his paper was to be discussed again, he should have due notice of the fact, and the opportunity of producing diagrams, tables, or other illustrative matter, in order that he might defend himself against any attack that might be made upon him. It was also

important that the Council should retain the power of deci whether such a renewal of a discussion should take place or because the Council was at considerable pains to get papers prep for certain meetings, and tried to accommodate the number of pa to the time given for discussion. If the resolution as origin proposed were to be carried, the conduct of the meeting would be al entirely taken out of the hands of the Council, who represented members, and were much better able to deal with those sma matters of detail, than the general body of members could be. was sure he was asking what the members of the Institution w readily grant—that such an amount of confidence should be place the discretion of the Council as the amendment expressed.

Mr. COCHRANE had much pleasure in seconding the amendm It was not always possible to get the reader of the paper present subsequent meeting; and if the original motion were carried, discussion might be re-opened in the absence of the gentleman alone could reply upon it.

The amendment was then put and carried.

The PRESIDENT announced that an invitation had been receive hold the Summer Meeting of the Institution at Barrow-in-Furn The proprietors of the large steel works there had intimated that would be very pleased to welcome the Institution; and they had received a direct and cordial invitation from the Mayor, Mr. Edw Wadham. He had himself seen Mr. J. T. Smith of Barrow, s time since, in reference to the matter, and had ascertained that arrangements could easily be carried out. He hoped that there w be a large attendance at Barrow, which was an excellent place for meeting. The great docks had lately been opened: there were steel works, ship-building yards, wire mills, and other works to seen; and he had no doubt the members would spend a few days pleasantly in the locality.

The following papers were then read:—

REPLY ON THE DISCUSSION UPON FIRELESS LOCOMOTIVES.

By M. LÉON FRANCQ, of Paris.

In submitting the following remarks upon the interesting discussion which took place at the last meeting of the Institution, the author wishes in the first place to thank the President and Members for the kind reception given to his original communication.

He fully concurs in the opinion of Mr. Crampton, that the chief heads of working cost, with tramway engines, are those for wages and maintenance. In practice this has everywhere been proved to be the case; and the main superiority of the Fireless Locomotive lies in the reduction which it effects as to wages, and in its economy as regards maintenance and repairs.

He admits that the working parts of the Fireless Engine are too near the ground; and has prepared designs for raising them higher, so as to save them from the effects of mud and dust. He wishes to remark however that the repairs required from this cause, on the fireless engines employed upon the Rueil and Marly-le-Roi Tramway, have been insignificant. This arises chiefly from the complete absence of ashes, and also from the arrangements made for doing away entirely with metal coverings to the mechanism; these latter being found, contrary to expectation, to retain the dust, which thence blows about among the parts of the engine; and thus to aggravate instead of diminishing the evil. The author would add that he cannot approve of the arrangement for raising the cylinders adopted by Mr. Brown of Winterthur. That it is defective is proved by the excessively bad condition in which these engines are now found to be. In the case of the Fireless Engine there are various other arrangements, by which it would be practicable to raise from the ground all the delicate parts of the mechanism.

In reply to Mr. Tomlinson, the author has not the l hesitation in maintaining that hot water may be advantageously usefully applied for working the trains on underground railw where the length of line does not exceed 12 to 15 miles, and w the gradients are similar to those of the Metropolitan Railway. support of that opinion he would remark that since 2000 litres of water (440 gallons) are found to produce motive force sufficien draw a load of the gross weight of 36 tons over a line 9 miles l 12,000 litres (2,640 gallons) would certainly do six times as m work, or more than sufficient to draw a train of the Metropol Railway, which weighs 100 tons. Therefore there are really two points to examine, (1) the power and rapidity with which engine can start, and (2) the possibility of storing 12,000 litre hot water on the engine. Now power and rapidity of starting be obtained in all cases with four cylinders, and perhaps on stra level lines with two cylinders of large diameter. Again the autl investigations show that it is possible to provide not only 12,000 litres of hot water on the engine, but also for a large quan of cold water for condensation. An engine on this system, ins of weighing 35 tons empty, need only weigh 26 tons; so tha working order a Fireless Engine for underground lines would weigh 43 tons. As to the possibility of charging the engines f stationary boilers, this would be easily accomplished by proportio the production of the boilers to the demands of the eng requiring to be charged in a given time. If in one hour, instance, it were necessary to charge twelve engines, each en ought to be filled in five minutes; this is merely a question of section of the steam feed-pipe, the size of which it would be neces to calculate. To charge twenty engines per hour, it would necessary to fit up at the terminus a set of stationary boilers ha an aggregate heating surface of 1800 square metres (19,400 sq. besides reserve boilers. This cannot be considered as impractica and though it might require some care and forethought to esta the system, great advantages would result from the concentratio the production of steam at a single point, from the abolitio stokers on the engines, and from the total suppression of delete

gases, which escape from the ordinary locomotives in the tunnels, and which greatly incommode the passengers, in spite of the ventilation produced by the passage of the trains.

With regard to the question of condensation, the author considers that to condense completely by air requires much too large a surface for practical use; and that to condense completely by water requires too great a supply. Other known methods of condensation are too costly. To keep within the bounds of practical, utility, the author would not attempt anything more than the suppression of the noise of the escaping steam, by causing it to expand in a large expansion chamber, and then condensing it partially, by contact with tubes having air circulating in them. He believes that, by thus completely withdrawing from the escaping steam all the water which it contains, the result, on underground lines, would be that the dry steam would rise promptly to the top of the tunnel, and would clear away with sufficient rapidity. Even admitting that a light vapour would sometimes find its way into the carriages, when the atmosphere was not favourable to the ascent of the steam, this would not produce serious inconvenience; for, while there are many people who avoid the London underground railways on account of the smoke, they certainly would not make the same objection to the occasional presence of a little pure steam. This, in the author's opinion, would be proved by experience, and would produce an important and rapid rise in the receipts.

For street tramways the author considers it possible to condense the exhaust steam completely; but he would ask whether its escape, *when unaccompanied with any noise*, is not rather an imaginary than a real inconvenience. The apparatus for complete condensation constitutes a source of complication, and consequently of expense, which takes away from tramway engines much of the advantages they are intended to realise, in simplicity and economy of working. He would add, that after five years' experience and consideration of the question, he is satisfied that animals are not frightened at the sight of steam; and that in reality they are more easily frightened by an engine which advances rapidly without the outward and visible signs of movement. They are also afraid of everything that produces a

shrill, sudden noise, as is the case with compressed-air engines, with ordinary locomotives, which cannot dispense either with violent escape of steam to increase the blast in the chimney, with safety valves, which are liable to blow off at any moment.

The author does not agree with Mr. Welch that the arrangem of the admission valves in the steam expander is likely to transf the heat of the steam into electricity. Sir William Armstrong cau electricity to be disengaged in his apparatus, only by using a v high pressure of steam, by cooling that steam so as to transform into vesicles of water before its escape into the atmosphere, by exciting considerable friction of these vesicles against one anoth It is known that the Armstrong electrical machine did not at produce the effect sought, as soon as the steam ceased to circul in the cooled pipes, and as soon as the friction of the vesicles water against one another no longer continued to take place. In Fireless Locomotive the balanced admission valves, from their annu form of outlet, cause very little friction; and the steam, instead escaping into the cold atmosphere, passes into a body of vapour high temperature and under considerable pressure, there to superheated; there is therefore no formation of vesicles of wa consequently no friction and no production of electricity. This been shown also by comparative experiments. The expander nothing else really than the slide-valve recommended by Mr. Wel only it acts automatically, whilst an ordinary slide-valve would so act. The author therefore must continue to consider the expan as advantageous, a fact of which he has convinced himself by l and minute observation.

On the question of the employment of steam at low pressure, author observes that his opinion is not shared by Mr. Cowper, nor several other members. He believes however that he is right on t important point, which he is glad to have submitted to the critic of the Members of the Institution. He agrees with Mr. Welc statement that steam at high pressure is more advantageous, beca its latent heat is lower, in proportion to the total heat produc than the latent heat of steam at low pressure. But in order t this advantage may really hold, it is necessary to assume t

the high-pressure steam has not given out a larger number of heat units into the atmosphere, after doing its work, than the low-pressure steam. We must therefore calculate for a locomotive within what limit expansion can advantageously be allowed, taking count also of the proportion of priming water carried over. The author considers that this limit is, on an average, two-thirds of the stroke. With these data it must then be seen what is the latent heat of the steam when it escapes from the cylinder, as compared with that of low-pressure steam; the difference is a loss of useful heat, given out into the air.

Taking account of these practical considerations, the author has calculated that in utilising the heat existing in steam, a locomotive engine—not a fixed engine, for it is necessary not to confound the two—gives an efficiency of 44 per cent. only with steam at 15 atmospheres, whilst the result is 60 per cent. with steam at 4 atmospheres. This difference of 16 per cent. is still further increased, if we compare the results of an engine working with high-pressure steam and delivering to the cylinders 30 per cent. of water in the vesicular state, and the undoubtedly better results of an engine working with low-pressure steam, and that steam dried by the means pointed out in the paper. The difference of 16 per cent., on the contrary, would be evidently diminished, if the comparison were made in the case of a stationary condensing engine of high expansion; but that which can be done by means of expansion in stationary engines cannot be done in ordinary locomotives, where the amount of priming water, the inconveniences of lead on the exhaust side, and the need of a strong current of steam in the chimney, are causes which necessitate a limitation of the expansion, and an increased loss of heat in the exhaust steam. Taking these things into account, the author was led to prepare a Table, on which the statements made at the end of his paper are based. He is thus of opinion that Mr. Cowper is in error in saying that steam generated at 15 atmospheres cannot be used at 4 atmospheres without great loss. Compare the case of the Fireless Locomotive with that of two vessels A and B, in communication with each other, of which A is filled with a supply of steam at 15 atmospheres, or at a temperature of 199°

Centigrade (390° Fahr.). If A is now put abruptly
communication with B, the pressure will equalise itself in
two vessels. If we suppose besides that the ratio between
two vessels is such that the common pressure in the tw
4 atmospheres (temperature 144° C., or 291° Fahr.), the an
of internal heat in the steam will not have changed, and no
will have been done. In the author's system the communic
is not made abruptly, but gradually, till equilibrium is establis
the result however is the same. Now according to the da
Zeuner's work on Heat, the internal heat of steam, saturated
dry, at 15 atmospheres or 199° C.,—in other words, the heat o
steam in the first vessel A,—is given by $573 \cdot 34 + (0 \cdot 2342 \times$
$= 619 \cdot 94$ calories per kilogram. The same steam, saturated
dry, at 4 atmospheres, occupying the content of the two vesse
and B, will possess an internal heat of $573 \cdot 34 + (0 \cdot 2342 \times$
$= 607 \cdot 06$ calories per kilogram. The difference between
quantities is $12 \cdot 88$ calories per kilogram : the steam at 4 atmosp
is therefore superheated by this amount, and this superheatin
the effect of vaporising the minute drops of water brought ov
the vesicular state.*

This would not be the case on the contrary if the steam exp
directly into the cylinders: the expansion would then pr
condensation, and the effect of the superheated steam in vapo
the water would not take place.

The author acknowledges that the question which he
submitted is a difficult one; but the statements advanced by
which were so much questioned, will shortly be verified by ca

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* Professor Clausius has pointed out to the author that there will alway
theoretical loss in expanding by an expansion chamber, because steam
expanding to a lower pressure, cannot by means of that lower press
compressed again up to its original higher pressure. The process is ther
non-reversible one, and by a well-known principle of Thermo-dynamics
reversible process cannot be the most efficient. The author considers th
loss due to this cause, as also to the friction of the steam in expanding,
found to be insignificant: but it may of course dispose of part or all of the
calories mentioned in the text.

experiments. These he proposes to make with a locomotive of one of the large railway companies, on which he will fix an apparatus that will give a sufficient draught for the fire, without requiring any great pressure in the exhaust steam.

As a practical reply however to the questions and criticisms which have been addressed to him, the author may state that he has run a fireless engine on the Rueil and Marly Tramway, with the same charge of steam as usual, sometimes simply suppressing the expander, and sometimes admitting steam by the regulator and then expanding it by the link motion according to the pressure required; and that *he has never found a greater consumption of steam with the expander than without.* He has observed that the superheated steam gives at its entrance to the cylinders a mechanical equivalent higher than ordinary; that the packings of the regulator and the pistons last longer than with the direct introduction of the steam; that the leakages of steam are less numerous; and that the steam exhausted at atmospheric pressure not only utilises its heat better, but also makes no noise, and is much more readily condensed.

ON BROWN'S TRAMWAY LOCOMOTIVE.

BY MR. B. C. BROWNE, OF NEWCASTLE-ON-TYNE.

The conditions that are required to be fulfilled in a Tram Locomotive over and above those of an ordinary locomotive tolerably well recognised, and may be enumerated as follows:—

(*a*) There must be no visible smoke or steam, no visible no noise of either blast or machinery, and no visible working p The object of all these restrictions is to avoid frightening h or annoying the public.

(*b*) The engine must work both ways, the driver being alwa a commanding position; it must be able to exert great powe starting and stopping on steep inclines, and must both start and very easily; it must run round sharp curves, and adapt itself t inequalities in the road; its working parts must be readily acces and easily repaired; its firing and feeding must need no atte while it is running; lastly, it must be worked of course by one These are matters of practice and economy.

(*c*) The Board of Trade requires beyond these a speed indi always visible to the driver, a governor, and a bell or whistl signalling.

The writer, having carefully considered these conditions, ca the conclusion that among existing engines they were best and economically met by the engine of Mr. Charles Brown of Winte mention of which has already been made in M. Mallet's paper before the Institution in Paris, in June 1878. This engine has w regularly in Geneva since the summer of 1877; in Milan sinc beginning of 1878; in Hamburg and Strasburg since the summ 1878; in Paris since the autumn of 1878; in Rome and Tivoli June 1879; in Ribeauville since August 1879; in Florence and (

Dronero since November 1879. In addition to the above places where the engines are in regular work, they have been, or are, running on probation at Lisbon, Oporto, Turin, Brussels, Berlin, Cologne, Madrid, Milan, Monza, Villa Regoa, and Villa Reale (Portugal). In most of the above places the consequence of these experiments has been that the question of steam traction versus animal traction has been decided in favour of the former; but the carrying of this decision into execution has been frequently impeded by the conditions imposed by the local authorities, or by financial difficulties.

I. *Description of the Engine* (Plates 1, 2, and 3).—The leading principle of this engine is that of working with very high pressure (220 lbs. per sq. in.). The boiler (Figs. 2 and 3) consists of a vertical cylinder A, containing the fire-box in its lower part. To this is riveted, opposite the fire-door, a horizontal barrel B with tubes, like that of an ordinary locomotive; this barrel is entirely below the water-level. The whole is made of steel, carefully selected and tested. The grate C is steeply inclined downwards from the fire-door, so as to increase its area and efficiency; and there is a drop-bar D at the bottom for letting down the fire. The ash-pan is provided with an ordinary door for regulating the draught. Owing to the height of the outer fire-box, there is a very great range of water-level (about 20 inches). Hence the driver need never attend to his fire or feed his boiler during the longest run usual on tramways.

The cylinders E are horizontal and above the foot-plate, the steam chest being below the cylinders, by which arrangement they are always kept clear of water. There is a great range of expansion. With valve-gear of the proportions indicated in Figs. 4 and 5, the distribution of steam is as shown in the Table annexed, the distances being expressed in percentage of the stroke of piston. The lead is constant at $\frac{3}{32}$ in.

	Admission.		Release before end of stroke.		Compressi	
	Fore. Per cent.	Back. Per cent.	Fore. Per cent.	Back. Per cent.	Fore. Per cent.	F Pe
Forwards . . .	76	80	7	4	6	
	67	67	10	7	10	
	49	47	16	14	20	
	26	24	27	26½	34½	
Stop	7	7½	44	42½	53	
Backwards . . .	21	22	29	27	35	
	47	50	16	14	19	
	66	70	9	8½	12	
	78	80	5	5	7	

In the engine shown the cylinders are 5½ in. diameter and 1 stroke. Each piston-rod works a rocking beam F, Fig. 1, whi means of a connecting-rod G at the other end, transmits the mov to the driving wheels, and thence by ordinary coupling-rods t leading wheels. All the pin-ends, lubricating holes &c., are car covered to keep out the dust. The valve-gear (described more below) is of a very simple description, entirely avoiding ecce links, or other sliding motions, so objectionable on account of mud &c. The rocking beams on each side, and the other wo parts, balance each other without the need of balance-weights o wheels. The motion of the engine is thus made very smooth free from oscillation or "galloping"—a very essential point a short wheel-base.

The whole of the working parts, as well as the boiler, a arranged as to be readily accessible for both cleaning and re Everything is made as light and strong as possible, and both and phosphor-bronze are largely used. The position of the cyli is very convenient, and very well sheltered from dust and dirt.

The hind axles support the weight of the engine by springs in the ordinary way; but the front axle has two sets of volute springs H, Figs. 2 and 3, placed together in the centre, so that the engine is practically supported on three points. On these springs the front axle has free play; and as side-play is also given to the axle-boxes, which are united by a frame, the engine runs very smoothly, while the four wheels all take a bearing on the roughest roads. The wheels are from 24 in. up to 28 in. diameter, according to the character of the line.

The water-tanks are placed between the frames. There is one I, Fig. 2, for the feed-water, which holds about 110 gallons; and a small one J for the condensed steam, holding about 30 gallons. The mode of disposing of the exhaust steam is as follows. The cylinders are fixed on the two ends of a cast-iron box K, which forms a support for the bottom of the smoke-box; into this the steam is exhausted, and in many cases is passed from thence direct into the chimney, into which it flows in an almost continuous noiseless stream. The chimney is very large, and has interior smaller chimneys of gradually increasing diameter. But if a condenser is required, which probably will almost always be the case in towns, the steam ascends to a layer of copper pipes L, which are arranged over the roof and kept cool by the air passing between them. The condensed steam flows down to the small tank J, which can be emptied at any convenient place at the end of the run or elsewhere. It is not allowed to mix with the feed-water, on account of the dirt and oil that would then get into and injure the boiler.

In Paris these engines have no condenser, and in Germany they sometimes have and sometimes have not; but in England the condenser will probably be always an absolute necessity.

The brakes are worked by hand, and are very strong; but in future all engines will be fitted with steam brakes. There is a pump and an injector for feeding, and the ordinary arrangement of sand-boxes. All the handles are arranged in duplicate, so that the engine can be worked equally well from either end. The driver always stands full in front. The engine is handled easily by one man, wherever the local authorities allow it; and practice has

proved that one man is sufficient. The couplings are central, and arranged to push and pull. When the engine runs against the car, the couplings come together, the driver drops in the coupling-pin from where he stands, and the connection is made. The fuel is coke. The weight of the engine loaded is about $6\frac{3}{4}$ tons.

II. *Description of the Valve-Gear.*—The valve-gear, as already mentioned, is very simple, and contains no parts liable to suffer from dust, mud &c. The distribution of steam is very correct both in fore and back gears, much better in fact than can be obtained by the common link motion, as a very slight inspection of the foregoing Table will show. Figs. 4 and 5, Plate 3, are diagrams of the valve-gear &c., which will serve to make the mode of action intelligible: Fig. 4, mid gear; Fig. 5, full lines, fore gear full; dotted lines, back gear full. It will be seen to have some similarity with Hackworth's or with Waelschaert's, but to differ from these in being worked off a pin situated at some point on the connecting-rod, and in requiring neither eccentrics nor cranks; further the new gear is furnished with several combinations which render it easy to eliminate any errors caused by the curved paths of the various parts composing the mechanism; indeed, by very carefully choosing the proportions, the distribution may be made nearly mathematically correct for each notch of the sector, as well in backward as in forward gear. The gear, as shown in the diagrams, is adapted to an engine fitted with a working beam; the motion is taken entirely from one point A in the connecting-rod, situated at about one-third of the length from the crank-pin end. The path described by this point is an ellipse with a curved major axis, the curvature being produced by the small end of the connecting-rod being constrained to move in the arc of a circle by the working beam; this curved ellipse serves to neutralise the error which would otherwise be present, arising from the curve described by the end of the pendulum lever B. The upper end C of this lever B is articulated to a system of radius rods D and E, forming a sort of parallel motion; E turning on a pivot at F, and D sliding in and out of an oscillating socket at G. Both E and D are attached

to the double-armed lever, or reversing shaft, H: this lever turns about the fixed point J, and can be set at any angle between full gear fore and full gear back, Fig. 5. The mechanism is connected to the slide-valve by the connecting-rod L from the point K, situated on the pendulum lever B at about one-eighth of its length from the upper end. The motion of D and E causes the ellipses described by the point K to have a curved major axis, and thus eliminates the error which would be caused by the angular motion of the rod L.

It will be seen in Fig. 4 that in mid gear the major axis of the ellipse described by the point K is nearly vertical, as shown to a larger scale at P; and that the motion imparted to the valve when the gear is in mid position scarcely exceeds the sum of the lap and lead at both ends, which is the amount of the space between the two dotted lines MM and NN. This amount of motion is consequently not sufficient to admit so much steam as that the engine will move.

Fig. 5 shows, in full lines, the reversing lever in full forward gear; the elliptical path of the point K, as shown enlarged at R, is now seen to be inclined, and to extend much beyond the limits of its horizontal travel in mid gear, Fig. 4. The areas of the parts of the ellipse R beyond the dotted lines MM and NN represent the amount and duration of the openings for entrance of steam, in this case amounting to about 76 to 80 per cent. of the stroke. By placing the reversing shaft in any position intermediate between full gear and mid gear, any desired amount of expansion may be obtained.

Fig. 5 shows also, in dotted lines, the position of the mechanism in full back gear; the operation of the gear in this position is the same as described for fore gear, only reversed.

The lead is constant for all positions of the reversing lever. For it will be seen on trial that the points C and J always coincide when the engine is on the dead points, in whatever position the reversing lever may be. A further advantage of this gear is that it is not much affected by the vertical play of the axles.

III. *Dimensions and particulars.*—The engine shown in the drawings is of the Type No. II., which is considered to be a useful

average size. It is the size most in use, and will haul with 15 tons up a gradient of 3 per cent., or 1 in 33. No doubt in many modifications will have to be made, to suit the va requirements of different towns and districts.

The principal dimensions and particulars of the three typ engines at present made are given in the following Table :—

Particulars of Engine.	Type No. I.	Type No. II.	Ty No.
Weight in working order without condenser	17,000 lb.	14,500 lb.	11,6
Weight in working order with condenser ...	18,300 lb.	15,500 lb.	12,3
Water in Tank	160 gals.	110 gals.	108
Weight of Fuel	270 lb.	224 lb.	180
Wheel base	5 ft.	5 ft.	4 ft.
Diameter of wheels	24 to 28 in.	24 to 28 in.	24 to
Diameter of cylinder	$6\frac{5}{16}$ in.	$5\frac{1}{2}$ in.	$4\frac{3}{4}$
Stroke	$11\frac{3}{4}$ in.	$11\frac{3}{4}$ in.	$11\frac{3}{4}$
Heating surface	130 sq. ft.	102 sq. ft.	81 s
Maximum pressure	220 lb.	220 lb.	220
Extreme length	12 ft. 3 in.	12 ft.	11
" breadth	6 ft. 6 in.	6 ft. 4 in.	6 ft.
" height	12 ft.	12 ft.	12
Tractive force with 24 in. wheels	3000 lb.	2300 lb.	170
" " " 28 in. "	2570 lb.	1970 lb.	145

IV. *Working Cost.*—As regards cost of working there is yet any actual experience in England. In Strasburg, where engine draws at different times two, three, and frequently four it is considered that, since a sufficient number of horses would to be kept to work the maximum traffic, the comparison betwee cost of engine-power and of horse-power is very greatly in favo

the former; and that, even where a fixed and regular traffic exists, the cost of engine-power is much less than that of horses.

It will require the experience of many years to arrive at anything like exact figures as to working cost. During a great part of the time for which these engines have been running they have been only feeling the way. The advantage of mechanical traction varies greatly with the nature of the traffic. When this is subject to great fluctuations, as in the case of Strasburg just mentioned, mechanical traction is enormously cheaper than animal traction; but on lines where the traffic is less fluctuating, and the service can be carried on by one-horse cars in rapid succession, the advantage of mechanical traction in the shape of a locomotive is less apparent. In such cases the combined car and engine would probably be more advantageous. On the other hand in cases of heavy gradients the advantage of mechanical traction is very great, as long heavy gradients are very ruinous to horses.

In Strasburg the Company has twelve engines of No. II. type. During the week six to eight engines are at work; but on Sundays often the whole twelve are running, as the traffic on the week-days does not average more than 40 per cent. of the Sunday traffic. The consumption of fuel and oil per engine, as well as the distance run, during four months in 1878, is shown in the annexed Table taken from the books of the Company:—

1878.	Fuel, including getting up steam.		Lubricating material.		Distance run per day and per engine.	Number of passengers per engine.
	Coke per hour.	Coal per day.	Oil per day.	Tallow per day.		
	Lbs.	Lbs.	Lbs.	Lbs.	Miles.	
August	20·00	16·00	2·80	0·00	51·00	771
September	23·00	67·20	2·25	1·06	49·20	680
October	25·25	70·25	2·96	1·13	48·50	604
November	30·50	83·00	3·30	0·81	44·80	560
Mean ...	24·68	59·11	2·82	0·75	48·37	654

The cost of working per day and per engine is as under, accordi
to the books of the Strasburg Company :—

	Marks or Shillings.
Redemption and Interest	4·80
Repairs and Cleaning	3·81
Coke and Coal	5·00
Oil, Tallow, and Packing	1·50
Wages of Driver	4·80
Total	19·91

This is equivalent to about £1 for 50 miles, or about 5*d*. per mile.

The arrangements at Strasburg for repairing and for conducti the traffic are very complete and under good control. The engi are regularly washed out at short intervals, and the smallest defe are made good immediately. The want of the above arrangemen together with a bad line, has been the cause of the abandonm of more than one attempt at introducing steam traction.

It is necessary to have from one-fourth to one-third m engines than are daily at work, so that repairs, washing o cleaning &c., may be done thoroughly, and also as a reserve contingencies; and on this assumption, the cost of working engines daily with two in reserve would be as under, taking Strasburg prices as correct :—

				Marks or Shillings.
Redemption and Interest on 8 engines, at			4·80	38·40
Eight Drivers,			„ 4·80	38·40
Repairs, Cleaning, &c., for 8 engines,			„ 3·81	30·48
Coke and Coal,	„ 6	„	„ 5·00	30·00
Oil and Tallow,	„ 6	„	„ 1·50	9·00
				146·28

Hence the daily cost for six engines in service and two in reserve
$\frac{146 \cdot 28}{6} = 24 \cdot 38$ shillings per engine working, or say 6*d*. per mile.

In case of the reserve engines being occasionally in service, daily cost per engine would be somewhat less.

The above refers to Strasburg, where the number of miles run small. We will now take another case, that of the Hamburg

Wandsbeck Tramway, where the service is more severe, the line in bad order, and the means of repairing very scanty; here each engine has to run 81 miles per day with 2 cars, or has 10 double trips per day. The consumption is 670 lb. of gas-coke per day, costing 6*s.* The daily outlay is as under:—

	Marks or Shillings.
Redemption and Interest	5·35
Repairs and Cleaning	4·50
Driver	4·50
Boy to help	2·00
Fuel	6·00
Oil and Tallow	1·70
Total, without reserve engines	24·05
For the reserve engines must be added one-third of the first four items, or	5·45
Total Daily Outlay, including reserve engines	29·50

This is equivalent to $4\frac{1}{2}d.$ per mile only.

We may compare the above with the cost of working the line with animal traction, which for 1877, according to the report of the Company, was as under:—

	Marks or Shillings.
Stable staff	58585·25
Stable working expenses, cleaning, &c.	7911·35
Oats	77205·87
Maize	96063·39
Hay	54629·86
Sundry forage	29066·95
Straw	21264·41
Sawdust	12269·00
Shoeing	24477·15
Harness	4892·30
Depreciation of horses	37624·73
" stable inventory	3478·24
Interest on the value of horses, 5 per cent. on 244900	12245·00
Gross total without drivers	439713·50
Deduct the value of the manure	10583·76
Net total without drivers	429129·74

For the year 1877 the total number of double trips made amounted to 118,911; so that we have:—

	Marks or Shillings
Cost per double trip without driver	3·695
Add cost of driver per double trip	0·375
Total per double trip	4·070

Hence 10 double trips (following the mode of calculating steam traction) would cost per day with animal traction 4(shillings, or 38 per cent. more than the cost with steam (29·5 There is the further advantage with steam traction of being abl haul more than one car at a time, which is not taken into considera in the above calculations. To make the difference clear, the grea number of persons carried at one time with horse traction would exceed 50 to 60, whilst with steam traction 100 to 120 persons in cars is not at all an uncommon number. In Strasburg 200 to passengers have often been carried in one train of four cars. Tal into consideration the ease with which two double-storied cars, f loaded, can be hauled by engine power, even on steep inclines, economical advantage of mechanical traction is very apparent. Tl

	Marks or Shillings
2 Cars with animal traction cost per day 40·70×2=	81·40
2 Cars with engine traction cost per day . .	29·50
Difference in favour of engine per day . .	51·90

In the above sum the outlay for conductors, car capital, and rep of cars &c., is not included, being the same in both cases.

According to later data obtained at Strasburg for a pe extending over a year's working, the result is as under :—

Repairs* per day and per engine, 4·60 marks or shillings.
Average work per engine per month, 1800 kilos or 1100 miles.
Average number of days' service per month, 19 to 20.
Average consumption of coke, 1·60 kg. per kilo. or 5·68 lb. per mile.
Lowest consumption of coke, 1·35 kg. per kilo. or 4·79 lb. per mile.
Lubricating material per day and per engine, 2·24 lb.
Load hauled, from 7½ to 16 tons over gradients up to 1 in 30.
Average speed, 12 kilos (or 7½ miles) per hour including stoppages.

* These include renewal of a number of tyres, some new springs, and small alterations, especially in the construction of the connecting and coup rod ends. These items, which will not recur, make the cost of repairs hi than in the first calculations.

In Hamburg the average load hauled is 15 tons over very undulating ground with few level stretches, and with gradients varying from 1 in 100 to 1 in 33. In Brussels, Turin, Florence, and Madrid, engines of No. II. size work inclines up to 1 in 15; and in Geneva a No. I. engine works regularly on a long gradient of 1 in 18, on which the rolling resistance is so great, in consequence of the sharp curves and the excessively dirty state of the rails, that it is often necessary to use steam even when descending. The load hauled is about 7 tons.

The number of engines actually built and at work up to the end of 1879 was 65, and about 20 more were then in course of construction. The oldest engine has been running at Geneva for about 2½ years. The average running consumption of coke with these engines, exclusive of getting up steam, is on level roads 1 kg. per kilometre, or 3·6 lb. per mile, with an average load of 10 tons, and a speed of 12 kilometres, or 7½ miles, per hour, including stoppages.

V. *Comparison with other systems.*—The established types of tramway engines naturally divide themselves into three classes: (1) The independent locomotive class; (2) The fireless locomotive, using steam; (3) The compressed-air engine. There are also gas engines &c., but none of these are before the public. The two last classes have in common the fact that they require to work from a fixed base or station; and the whole history of the railway system goes to show that in the long run, wherever they compete on equal terms, the self-contained locomotive is more economical and more efficient than any arrangement which involves stationary plant. As regards the fireless locomotive, many of the advantages claimed for it are also possessed by the Brown locomotive, since this also carries steam at a high pressure, and only needs attention to fire and water at long intervals. No doubt in places such as docks and warehouses, where fire is absolutely forbidden, the fireless locomotive would be valuable; and, to carry out the same principle, among bales of cotton, in grain warehouses, or other places where steam or damp of any kind is objectionable, compressed air will be the obvious motive power. Compressed air will also probably be the motive power underground.

As regards the advantages of a combined car and engine, when all is considered, the single real advantage in favour of the combination seems to be that of additional adhesion; and this is only obtained either by coupling many wheels together, which is inconvenient in tramway work, or by putting more weight on each wheel, which is looked on with ill favour by the owners of tramways, whose roads are generally unfit for any additional load. Still there are cases where this construction seems advisable; or rather perhaps the adoption of some of the arrangements by which the weight of one end of the car is borne by the engine. Mr. Charles Brown has built cars on this principle, where the car is carried by the engine at one end and by a bogey at the other. There are several admitted drawbacks to a combined car and engine, *e.g.*, that any repairs to the engine lay the car also off work, that the car has to go into the workshops where it is liable to get dirty, that different descriptions of cars cannot be used for different occasions without great extra outlay in plant, that each engine can take only one car, and that the combined engine and car is very troublesome and heavy if it gets off the line. Nor is there any obvious saving in first cost.

Lastly, we have to consider simple tramway locomotives. Both theory and practice show that in many points we must not be too closely confined by the recognised traditions of locomotive work. Possibly even in ordinary tank locomotives, for slow speeds and bad roads, there is too much resemblance in detail to the strong and comparatively rigid main-line engine, designed for good roads and high speeds. A light tramway engine cannot afford to depart from the most favourable conditions for traction and self-preservation; thus in the Brown engine the arrangements of the springs and axle-boxes are designed with the view of keeping the four wheels constantly on the road, and of making the engine run smoothly. Similarly the other parts, as described above, are all considered with a view to the special requirements of the work to be done. In fact daily experience seems to suggest, not that tramway engines will return to the type of the common locomotive, but rather that in many cases several of the special features of the Brown tramway engine may not impossibly be adopted with advantage in some of the classes of engines designed for railway work.

Discussion.

MR. B. C. BROWNE wished to observe that the statement on p. 47 of the paper—"In future all engines will be fitted with steam brakes"—applied only to those made for English use, the Board of Trade having expressed a strong opinion in favour of steam brakes. For that reason, and perhaps for that reason only, it was desired to use them. With regard to some of the Tables printed in the paper, he had been asked why they were not always put in the form in which it was easiest to compare them with each other. The reason was that they were all taken as exactly as possible from books or reports of various tramway companies. Of course, in running these engines in England, he had had to make some small additions, simply to meet the Board of Trade requirements; *e.g.*, to put on a speed indicator and a governor, and also to close in the sides. He had preferred however to submit the engine to the Institution simply as Mr. Brown himself had made it, without putting in those small matters which he had added, but which might be taken away at any time and had no special interest in them. He would add that if any gentleman wished to see the engine at work, he could do so, since by the kindness of Mr. Webb it would be exhibited on the following morning at 11 o'clock near the Willesden station.

MR. HENRY HUGHES said he had been running an engine in the public streets twelve months before the Brown engine was brought out; and he could not adopt the author's conclusion, that Mr. Brown's engine was the best that had been brought out for tramway purposes. In many respects he considered it to be the worst. For instance, he considered it a mistake to work in the public streets with 220 lbs. of steam. It was well known that with very high pressures it was very difficult work to run along the public streets. The jar of running over stones injured the pipes, and there was great difficulty in keeping the pipes and joints sound. Any gentleman who had had experience

in the bursting of tubes would know that it was a very awkw thing for the driver and passengers if a tube should burst under lbs. pressure. Again, he considered the fire-box was not designed to stand so great a pressure, and especially that the b just under the tube-plate, at the junction between the vertical horizontal parts, was a very weak point in the construction. He thought that more stays ought to be put in above the fire-box; perhaps that was only an omission in the drawing. That was believed, a design of boiler very commonly used, and very conveni for portable steam engines; and a very good one for giving a g range of water-level above the fire-box. He did not think it economical (although the amount of fuel consumed was said in paper to be very small), because of the shortness of the tubes. supposed that the tubes were made short and the pressure high order to produce a great heat in the chimney, and thus to super the exhaust steam, so that it might not be seen in the streets. Bu ordinary locomotive boiler could be made to do exactly the same simply lengthening the barrel and putting a large dome in the mid and he believed it would then be a better boiler and more useful tramway work.

The position of the cylinders he did not consider an improvem He did not think it very important to keep the cylinders so much of dust and dirt: he believed that the blame had often been thr on dust and dirt, when it ought to have been attributed to workmanship in the engines. An express locomotive was o covered with sand in its journey, by passing at high speed through atmosphere containing a great quantity of sand; and yet very li damage was done to it.

Some merit had been claimed because the axle-boxes were m to move laterally within the horn blocks. It was no doubt necess for tramway work to give the axle-boxes some lateral movem but he thought that could be done without any complication machinery, or anything peculiar in the springs. He understood the springs used were spiral springs, which he thought were worst sort that could be used upon tramways, because the section so small, only ½ in. or ⅝ in. diameter.

Mr. B. C. BROWNE said that there were spiral springs on the front axle, but ordinary leaf springs on the hind axle.

Mr. HUGHES believed that Mr. Brown used to have them all spiral, but he supposed he had found out the difficulty just alluded to. Spiral springs would not do for tramway work. The ordinary leaf spring had a very great section, and offered great resistance, whereas spiral springs broke through rapidly; and if one went, the rest would very soon follow.

There was a great objection also to the form of condenser shown. There were evidently two opposing tendencies at work, one to make the steam in the chimney as hot as possible, so as to become invisible, and the other to take the steam into a condenser, in order to condense it. The tubes, as shown, were not at all sufficient for condensing the steam that would be used; he did not believe that a twentieth part of it would be so condensed. The weight of brass which was carried in those tubes would be far better carried as cold water, in that it would condense much more steam. He had himself tried all sorts of condensers, and had calculated the time which tubes tock to condense, and the amount of water required to condense steam from certain classes of engines. He had tried mixing the air directly with the steam, but by that means he only produced a cold London fog. He had come at last to the conclusion that there was no better way of getting rid of steam in a tramway engine, than by sending it into a closed cold-water tank and confining it there. If there was any exit into the air, the steam would be sure to show. It might be possible for a certain distance on a level to condense the steam in the tubes shown; but when going up a gradient of 1 in 20, perhaps ten times the previous amount of steam would be required, and then the engine would puff out steam enough to fill the street, which in a place like Glasgow or London would certainly not be allowed.

Another small point was that, for the sake of the drivers, the engine should always be cased in at the ends, as well as at the sides, which was not done with the engine described.

... mile. Was it possible to ru
tramway, where the resistances we
were on a railway, using only $3\frac{1}{2}$ lb.

The paper stated that in this
obtained of the cost of working; l
accounts for three years on the Vale
were working in Glasgow; and fron
it might be taken for granted that on
five pence per mile.

Turning now to the difficulties that
tramways by steam, he would first
tramways which had been laid in ear.
successfully on a bad tramway was ho
crossings should be particularly atten
order; because the wheels were apt
the crossings, and so make the engine t
caused by stones, bits of wood &c., the
be contended with: such things prod
engine, and he thought some simple me
them out of the way. The chief poi
drivers and good management. If eng
good managers and drivers were emplo
From the experience ...

large wheels and large cylinders, and by doing so a very great reduction in the piston speed would be obtained. The last fifteen engines that he had himself designed, were running at half the speed of the previous ones. The power might be increased at any time by reducing the size of the wheels, but the ordinary traffic could be worked even with a 4-foot wheel, without any inconvenience to the engines, and with a very greatly reduced amount of wear and tear: and wear and tear after all was the great element of cost in a tramway engine. There should also be very few parts in such an engine. In the engine before them the rocking beam was an addition that might be dispensed with. He had himself seen, on this engine in Paris, $\frac{3}{4}$ in. of play between the end of the lower connecting rod and the pin of the rocking beam; and he was then informed by the government inspector that the engine worked very well, but that he was going to couple the cylinder direct on to the crank-pin, and then it would be a very good engine indeed.

He should like to add a few remarks upon a very extraordinary accident that had occurred to his own engines. Twelve of those engines were taken to Paris, and in about a fortnight eleven of them were *hors de combat.* Previously to this one of the same engines had been worked constantly for a month, and had worked remarkably well. The water then used was that from the Seine at the Bastille; the cylinders were oiled with suet, and the engine was worked by the company's own men. It worked so satisfactorily during the month, that twelve engines were ordered. Some of these were run by his own drivers, and some by French drivers, and the water was taken from the Seine and the Marne. Not one of those engines would stand five days. He was assured that no oil had been used for the cylinders from the first; and certainly nothing but suet had been used on the experimental engine, which yet was one of those that gave way. In some cases the tubes completely broke off, and the whole contents of the boiler came out in the street. In some the tube-plate would bulge in, in the centre below the tubes, and in some the fire-box itself was bent. The failure was not gradual, but instantaneous. The engine would be going one way perfectly sound, and would come back almost directly

all wrong; and would then go back again quite right. He ca
in the assistance of M. Tresca, who said that the cause was u
expansion of the tubes and fire-box; that the boiler was made
stiff in the outside shell, and that the expansion of the tubes
the fire-box prevented the tubes from having their proper
on the tube-plate; therefore the tube-plate, from the pressur
the steam within, pressed outwards and bulged out below the tu
causing them to bend and break off. M. Banderali of the Nort
Railway was also kind enough to take great interest in the ma
sending his men to repair the engine at cost price; and he c
not believe in its being anything but that the workmanship of
boiler was not good. Of course he himself knew that it could
be bad workmanship, because he had had boilers which had wo
three years without the slightest leakage. Most of the Fr
boiler-makers refused to believe that, and wished to put in
fire-boxes; but he knew that those fire-boxes had stood
pressure of 17 atmospheres under the Government inspectio
Paris. However M. Banderali repaired the engine perfectly;
although the work was done by excellent men, some of whom
been engaged in similar work for the last fifteen years, it did
last three hours. It was again repaired, and it again gave way.
last he was obliged to come to the conclusion that oil had
put into the boilers. For the axles, an oil containing anima
had been found to answer remarkably well, because it had g
consistency and did not run through the bearings readily. Ou
the suet cups was inscribed "suet" in English, in order to pre
any of this oil being put into the cylinders; but probably the Fr
drivers had mistaken the meaning of this; at all events they
taken care to pour plenty of oil into the boiler through the
cups, and no doubt that formed a calcareous soap, and caused al
mischief. When the tubes were taken out however the calcar
matter was perfectly dry, and could not be seen to contain any f
all; but when it was put into a crucible and burned, the fat coul
smelt. The boilers had since been washed out with muriatic a
and a separate tank had been put on for the condensing wate
Mr. Brown had done. The boilers were now fed with pure w
and he believed that they would have no more difficulty in the ma

Mr. F. C. WINBY said that tramways had generally been made too light to carry locomotives. Some time ago he had observed the tramway engines running in Paris, and noticed that the road was knocking the engines to pieces, and the engines were knocking the road to pieces; but there was now no difficulty in laying down a line, with an improved section of rail, that would carry the heaviest locomotives. The features that had to be looked to in designing a tramway locomotive were—to bring the weight well upon four wheels, with not more than 5 ft. wheel base, which was the utmost limit that would pass round curves of 35 ft. radius; to condense the steam; to make as little noise as possible; and to keep the machinery well above the ground. It occurred to him that in Brown's locomotive a better arrangement might have been an intermediate crank-shaft close to the fire-box, acting by a connecting rod on the leading wheel. With regard to the valve arrangement, he saw no advantage over the ordinary valve-gear; for the number of joints and levers used would, in wearing, produce collectively a very considerable play in the connection between the pistons and the valves. It had occurred to him also that a good condensing arrangement might be made by using a water tank having a number of tubes passing through it, like an ordinary surface condenser, and by forcing a quantity of air through those tubes, to absorb the heat. On a line he had recently constructed, which ran $\frac{3}{4}$ mile up an average gradient of 1 in 20, and then $2\frac{1}{2}$ miles down hill, some mode of storing up power was much wanted, so that what was gained in the descent might be utilised in the ascent, when returning.

Mr. W. SCHÖNHEYDER had observed from the drawings that in communicating the motion from the cylinder to the rocking beam F (Fig. 1) a dog-link was used. He thought that was very objectionable, because it was impossible to get sufficient wearing surface for the block in the link. He did not know what the size of the block was in that case, but with $5\frac{1}{2}$-inch cylinders, giving a piston surface of about 24 sq. ins., and with 220 lbs. pressure per sq. in., there would be a total pressure of about 5300 lbs. on the piston. Probably the block would only have about 10 sq. in. of surface; so that there would be

over 500 lbs. per sq. in. upon it. No surface of that description would stand such a pressure. The same action went on there as in the guide bars for cross-heads, where it was known that the pressure should not be much higher than 40 lbs. per sq. in.; so that a block of that description must necessarily wear very fast; and from the remarks of Mr. Hughes it appeared that these blocks had actually worn very badly in Paris. In Figs. 4 and 5, Plate 3, he saw that a better construction had been substituted.

Another point to which he would refer was the boiler. If a boiler of that construction was to stand 220 lbs. per sq. in., it must be constructed of enormously strong plates, because the angle connecting the horizontal with the upright part formed a very weak point. It was the old story over again of the dome placed upon a Cornish boiler, and the whole of the metal cut away to make room for it. How such a boiler could stand 220 lbs., without very strong stays or some enormous thickness of plates, he could not understand.

Mr. W. LYSTER HOLT observed that on page 51 a statement was given of the consumption of coke and coal for four months at Strasburg; and it was very remarkable that in each successive month the consumption of both coke and coal increased, while the mileage of the engines and the number of passengers decreased. That, as it seemed to him, could only be accounted for in two ways. Either the engines rapidly deteriorated, or else there was something radically wrong in the distribution of the steam. Perhaps the wear and tear was greater than it would be with ordinary eccentrics and link motion. Then he noticed that on page 52 the cost per mile was given as 5*d*. He could only say that the tramway companies in Paris would be only too glad to let the whole of their tramways at 7*d*. per mile, to be worked by any contractor who would supply the engines.

With these engines the same difficulty occurred as with all other tramway engines, namely, the enormous expense of repairs. He included in this the redemption and interest, which, as he understood it, would mean renewals. According to the paper the repairs and renewals would cost over 2*d*. per mile out of 5*d*., or over 40 per cent.

He noticed also that on the Hamburg and Wandsbeck tramway, where the service was more severe, and the engine ran 81 miles per day, the consumption averaged 670 lbs. of gas coke per day, or considerably over 8 lbs. per mile. His experience in Paris was that this was about the average consumption there. Therefore there was nothing economical in the engine which they were considering. He could not see how that consumption, in actual work, of very nearly 8¼ lbs. per mile could be reconciled with the statement on page 55, that the average running consumption of coke with these engines was only 3·6 lbs. per mile. If such a result could be arrived at, he need hardly say that steam would very soon replace horses, as no doubt it would eventually.

It was observed on page 44, regarding the qualifications of a tramway engine, "Lastly, it must be worked of course by one man." His own experience in Paris had been that it would be absolutely dangerous to work with one man in crowded thoroughfares. A tramway driver, the moment he had started his engine, could not pay any attention to the engine itself; he had to look to the street crossings, and matters of that kind: and he questioned whether even on a railway, where the driver had less to do, any locomotive superintendent would advocate running an engine with one man. In running one way, with Brown's engine, the man was at the smoke-box end, and consequently he was right away from his fire door. That would not so much matter when the engines were new; but after running a certain time locomotives were apt to leak, and tubes to burst, and the man would not be near to plug them up. It was well known too that tramway locomotives had a disagreeable habit of priming; but the driver, being sheltered by the cover, did not feel the effects of that priming, and often knew nothing about it. His belief was that half the accidents which had occurred to tramway locomotives through shortness of water, had been caused by the simple fact that the driver thought he had got a boilerful of water, when it had primed away. He did not take the trouble to look at his gauge glass: in fact he had not time to do so, having to look out to prevent accidents; and so he was suddenly astonished by the safety plug burning out. He was speaking of things that had happened

perhaps once a week. In his opinion therefore it was a mista leave the engine with only one man. There might be a small as in Paris, to blow the horn and look after the fire; but there be a thoroughly competent man whose sole attention, or at leas greater part of it, must be given to the engine, as in the case ordinary locomotive.

The Brown engine certainly possessed one good feature i machinery being raised from the ground; for his own experienc been that, apart from the defects of the road, dust had been the enemy of tramway engines. It must be remembered that wi ordinary tramway locomotive the crank and the big end o connecting-rod and the eccentric straps sometimes came within of the ground: as for instance with the engines working at F and Paris, having inside cylinders of 7 in. diameter and 11 in. st and wheels 2 ft. diameter on tread when new. Moreover a tra rail was not like the raised rail of an ordinary railway, but was level with the ground, and had a groove in which the dust and accumulated, to be churned up by the wheels. This was no point, because the same evil occurred in India, with a very dif sort of service, as Mr. Crompton had informed them (Proceed 1879, p. 503). Further he believed it to be a well-known fac in very small narrow-gauge locomotives, where the machiner very near the ground, it had been observed that after even onl days' service the brasses &c. had been completely worn and cut thr Unfortunately the paper gave no statistics as to the cost of wo Mr. Brown's engines in Paris. Had it done so, they would pro have been able to compare it with the cost of working three o ordinary types of engines, such as Merryweather's, Fox Wall Co.'s, and the Compagnie de Fives-Lille's engines. He di know whether Mr. Brown's engines were running now in Pari if they were it would be interesting to learn what they were doing, because other engines with six wheels, constructed in Bel had been lately running on the same line; and that line constructed better than the generality of tramways in Underneath the longitudinal timbers were cross sleepers, simil those in the tramways at Rouen.

They had heard from Mr. Hughes that he had suffered very much from the fire-boxes of his engines in Paris giving out. For two years he (Mr. Holt) had used for his engines the same water as Mr. Hughes had employed, and did not experience the same effects; but he did not condense. This point was certainly one that required some investigation, because the experience was so contrary to that of the Metropolitan and District Railways. So far as he was aware, it was not found there that the introduction of oil and tallow had any hurtful effect on the engines. In fact he had heard one locomotive superintendent say that it was an advantage, as he did not use so much oil and tallow as he otherwise should.

Mr. R. E. B. CROMPTON, referring to Mr. Hughes' observations about large wheels, said that all engineers would put large wheels on tramway engines if they could; but large wheels, without corresponding increase in length of stroke and consequent increase in general dimensions, meant slow piston-speed, and the piston-speed was very small in tramway engines already; it was not desirable therefore to decrease it, if it could be helped. He wished to protest against Mr. Hughes' objection to high pressures. Mr. Brown had apparently succeeded in carrying his pressure of 220 lbs. without any extraordinary trouble. No doubt with that construction of boiler it might be supposed that under 220 lbs. pressure there would be considerable distortion at the junction of the vertical and horizontal parts; but he had no doubt that by using strong flanges or angle-iron rings Mr. Brown had prevented that.

The arrangement for condensing the steam did not seem sufficient. Mr. Tomlinson, in speaking on M. Francq's paper at Manchester (Proceedings 1879, p. 630), said that with a condensing surface of 1600 sq. ft., or considerably more than the heating surface in the boiler, he did not condense one-tenth of the steam. He was himself present at several trials made some years ago with Mr. Perkins' small road locomotives, working at about 500 lbs. pressure; and there an air condenser was required that weighed nearly as much as the whole engine besides, in order to condense the whole of the steam. The condenser shown to the meeting would, he thought, do

more harm than good. The steam that escaped would come out in a very visible form. As far as his experience of engines on roads went, the best way of getting rid of the steam was not to attempt to condense it at all, but to keep it as long a time as possible in contact with the heated gases, and so superheat it. That answered in every way, except in very moist atmospheres, and there, do what they might, they could not get rid of the steam. He had been present at several trials of tramway locomotives in Leeds; and he found that the steam was not visible in the high parts of the town, but directly the engine got to the lower parts, the steam showed itself in dense clouds.

He noticed that Mr. Brown had made his boiler as nearly a vertical boiler as possible. He did not see why it should not be a vertical boiler altogether; that would get rid of any trouble there might be at the connection with the horizontal part, and would make it a great deal cheaper. He was convinced that for tramway purposes, where height was not so important a matter, and the boiler might stand as high as the tramcar itself, the cheapest thing that could be put in was a vertical boiler. The question of steam on tramways would not be solved until somebody produced a cheap engine; and none of the engines as yet produced had at all approached the point required. Probably the Brown engine cost the maker £700 or £800; while, as he had tried to show at the Paris meeting (Proceedings 1878, page 431), it would be impossible to compete with horses in England, where cars had to be run at short intervals, until the cost was brought down to about £300.

Mr. HOLMES HIRD said the author stated in page 49 of the paper that the valve-gear was not much affected by the vertical play of the axles. He happened to have had some experience of valve-gears, and it appeared to him that the vertical play of the axles in this case would affect the working of the valve-gear. In reference to the question of larger wheels, there was this disadvantage in them, that they would involve the necessity of larger cylinders, and much stronger and heavier working gear: the framing and wheels would also have to be considerably heavier. This addition to the weight was a very important matter in a tramway engine.

Mr. J. D. LARSEN had closely observed these engines from the time when they began to run in Paris, and so far they had given every satisfaction. Where they had failed, so far as he had observed, the fault lay in the road. If that was in fair condition the engines were all right; but they went at rather a high speed, and whenever they came to an inequality in the rails they sustained a shock that tended to knock them to pieces. He was in Hamburg last June, and the engines there were working very well; but they also, as Mr. Browne would admit, met with some difficulties, because they were too slight for a bad road. For new tramways such engines would no doubt answer admirably. He wished to know if Mr. Browne could state the working expenses in Paris. He had taken great interest in the Brown engine, and, so far as he knew, it had done better than any other engine for tramways.

Mr. D. HALPIN, referring to Mr. Hird's observations about the valve-gear, thought, if the motion were analysed, it would become evident that the vertical motion of the axle could not have much effect on the valve motion. The point where the attachment to the connecting-rod was made, for imparting motion to the valve-gear, was stated to be at about one-third of the length of the connecting-rod: consequently at that point the motion would only be one-third of the whole of the vertical motion due to the springs; and taking into consideration the further reductions due to the link-work, the versed-sine of the arc produced would be almost nil.

Mr. T. R. CRAMPTON thought that the vertical movement of the axles had practically no effect. With regard to the bearing surface on the end of the piston rod, that might be increased by making the loop longer. It was very important to have a large surface there, to prevent undue wear; but there was no doubt in his mind that the valve-gear shown, if properly made, would answer all practical purposes. It had also the advantage of giving the rocking lever, when going quickly, a proper balance. He did not however attach any importance to such points: the production of a good engine was not a serious difficulty. Attention should chiefly be directed to the road. In his

opinion a tramway road should be very much stronger, not li than the ordinary railroad. Heavy cars were running over it times; there were serious shocks from vehicles passing alon common road over the rails; and he thought therefore conside more would have to be expended on tramways than had been us regarded as necessary.

With respect to the engine itself, a tramway could never be in the same order as an ordinary road; and it was very ess therefore to have proper arrangements of springs, so that, unde conditions of the road, there might always be the same weight o wheels. That was best attained by the three-point system us Mr. Brown; and it could be carried out with six wheels as we with four.

It was his impression that there was also a future for the Fi engine described at the last meeting, because it was exceed simple in construction; and whether it burned a little more or not was of no very great importance. According to the only 3 or 4 lbs. of fuel were used per mile in the Brown en yet the total expenses were 5*d.* per mile, so that the fuel was about 10 per cent. of the whole cost. If 2 or 3 per cent. of was saved, and 20 per cent. more was expended on repairs, thr extra wear and tear, was the saving worth having at the price?

He agreed with Mr. Hughes in regard to the size of the wl In a tramway it was desirable to reduce the wear and tear, an keep out of the dust as much as possible; and he preferred to direct by increasing the size of wheel, rather than have complica or additional parts. As the members no doubt knew, he had some attention years ago to the use of a separate crank-axle, in certain conditions it was an admirable thing; but if the could be well balanced, and radiating axles employed, the arrange he thought would work well as it stood. With very small wheels parts must be close to the ground, and the pistons must be run fa In a tram engine, going only 8 or 10 miles an hour, the incr piston-speed was not perhaps injurious; but the increased ex due to wear and tear was very great. Large wheels involved a extra weight; but the extra cost of labour in their constru compared with the total cost of the engine, would be trifling.

A remark had been made with regard to short tubes. Mistakes were often made as to what was short and what was long in a tube. The question simply was, how large was the area as compared with the length. A tube 3 ft. or 4 ft. long might be a very long tube if it were only ½ in. diameter; at least there would not be much heat at the smoke-box end with those proportions.

There was one other point to be mentioned, that of the coning of the wheels. Of course in passing round sharp curves, with a small wheel-base, it was only the flange of the fore wheel that was in contact with the outer rail. The flange of the hind wheel was in contact with the inner rail; therefore in that wheel the large end of the cone was grinding round upon the inner rail. If that matter were looked at a little, it would be found that it would be much better if the wheels were made parallel. There would be less friction, the curves would be more easily passed, and there would be less wear and tear. Some twenty years ago he had induced Mr. Haswell of Vienna to alter his whole system, and to use parallel rails and parallel wheels. Mr. Haswell afterwards wrote to him to say that his wear and tear of tyres was 30 per cent. less than with the coned wheels.

Mr. S. ALLEY had closely watched the working of steam on tramways for about three years, on the Vale of Clyde Tramways at Glasgow; and agreed with many of the gentlemen who had spoken, that the matter of greatest importance was the construction of the road. The roads in general use were much too light. He thought Mr. Brown had made a mistake in making an engine that would adapt itself to a bad road. It was the roads that ought to be put right, and the making of such engines only encouraged companies to make bad roads. With reference to the condenser, he should like to ask Mr. Brown what was the weight of his condenser, working with an atmospheric temperature of 45° or 50° Fahr., *i.e.* what weight of tubes would be required to condense the steam thoroughly.

It had been remarked by Mr. Holt that it was not desirable to work an engine with one man. He could testify that for three years the engines on the Vale of Clyde Tramways had been worked by one man, and he did not know that a single accident had occurred, either through priming or anything else.

The matter that Mr. Hughes had mentioned with regard to locomotives in Paris was curious and interesting. Mr. Hughes consulted him about it, and at first, when he heard that the gradie were 1 in 10, he said that one end of the fire-box must be out the water owing to the inclination. But having learned that gradient of 1 in 10 was very short, and that the explosions did often take place on this incline, he saw that that cause could h little effect. Eight boilers exactly the same as those in Paris been at work on the Vale of Clyde tramways for three ye apparently under the same conditions; and in no case had they gi any trouble, further than a few ordinary leakages, which were ea cured. These explosions in Paris appeared to have been aln instantaneous, as if by minute charges of dynamite; and it there would seem to be more a chemical than a mechanical quest and one which ought, if possible, to be probed to the bottom.

Mr. DANIEL ADAMSON thought the matter could be sin explained by the action of the Paris water, which would be dr from the coralline oolites. All water highly impregnated with l whether carbonate of lime or sulphate of lime, had in its p character an enormous affinity for grease; and if there was grease in the boiler when it was heated, the lime deposit would hold of it. The grease could then only be detected in the Mr. Hughes had described, by putting the dust into an iron l heating it on the fire. The grease thus mixed with the lime could not be vaporised off the surface of the boiler plates unt temperature was attained of about 600°: and this temperature, w was that of a low red heat in the dark, would destroy the w tenacity of the brass tubes, and, as had just been said, they w break off and explode almost as if by dynamite. But besides the greasy dust would adhere even to the under side of the tu which would get so overheated as to destroy the bearing power only of brass, which was most treacherous at a high tempera but of wrought iron or the finest mild steel. Boilers workin the Wear at Sunderland and at Hartlepool, supplied from magnesian limestone, and, in some few cases, boilers working

well water at Birmingham, and getting sulphate of lime from the triassic rocks, had experienced the same evil. This subject was well understood by a few engineers of large experience in stationary engines, and no doubt remained upon it. Similarly when surface condensation was adopted for marine boilers, the grease played a most active part in destroying the tubes; a greasy sedimentary deposit settled down, sometimes on one portion and sometimes on another, in the most erratic manner, and corroded a hole through in a few days.

He must add his testimony as to the weakness of the Brown boiler. The horizontal casing attached to a vertical boiler necessarily made a weak part at the joining of the two. The great experience on railways had shown that there were only two forms of surface that could be constructed with certainty. One was that of a cylinder, and the other that of a perfectly flat surface, where the bursting action was neutralised by means of stays. He had had great opportunities of watching this T construction of boiler under test, and also in actual working on the Stockton and Darlington Railway; and nothing could keep such boilers tight in the angle between the two parts for any long period of time. The simple explanation was, that if there was a curved surface, which yet was not a true circle, it would always tend to get into a circle under pressure, and leakage would follow, unless the structure was heavily stayed.

He could not agree that the working beam was any advantage to the engine. He did not see how it was possible to transmit the force from the piston through that lever without excessive weight, owing to the necessity for strength. If it was practically possible to have a rather larger and heavier wheel, and make the crank sufficiently large to get proper piston-speed, it must be evident that the engine would then be worked with the fewest possible parts, and the least chances of wear and tear. He did not quite acquiesce in the statement in the paper that the vertical action of the springs would not affect the valve-gear. Those who were familiar with Hackworth's single-eccentric reversing motion, knew that it could not be applied to a locomotive from the dancing of the springs; and the principles of the two were identical.

Mr. R. PEACOCK, referring to the question of grease getting i
boilers, observed that the Metropolitan Railway engines, which
been working for fifteen or sixteen years, were still working witho
change of either fire-box or boiler; and it was well known that th
engines practically condensed all their steam, and that their boi
were fed from the condensed water. As a matter of course
water was greatly impregnated with the oil and grease that
put into the cylinders in the first instance, passed from thence
the condensed water, was taken up again by the pumps, forced
the boiler, and used over and over again. But with all that, it
the fact, he believed, that there were no other boilers so free f
scale and dirt as those of the Metropolitan Railway. He was
that the fire-box tops and sides, though some had been at work six
years, were as clean now as when they were put in.

Mr. JOSEPH TOMLINSON, JUN., said Mr. Peacock was under a l
misapprehension on the point he had raised, for this reason,
on the Metropolitan Railway only $\frac{1}{2}$ lb. of tallow was used
each pair of cylinders in a run of 100 miles, or $4\frac{1}{2}$ trips;
during that time the water was changed nine times, so that $\frac{1}{2}$ l
tallow was put into 8000 gallons of water. Moreover, as the steam
exhausted into the top of the tank, the grease being lighter rema
on the top of the water, while the boiler was fed from the botto
the tank; so that little or no grease ever got into the boilers. It
quite true that they had not put a new fire-box into any of
engines, though some of them had run over 600,000 miles;
they were almost as clean now as when new. He did not t
however that this arose from the cause suggested, but from
construction of the fire-boxes, and the manner in which they
stayed. The steam was more easily liberated longitudinally
vertically. The roof bars were set very close together, wi
$1\frac{1}{4}$ in. stay between them; and the steam ran along the top of the
box, under these stays and between the roof bars, and so kept th
of the fire-box clean.

Mr. CHARLES COCHRANE said that, with regard to the question of acid arising from the oil getting into the condensed water, he should like to give the result of twenty years' experience with boilers in the North, which were found to be pitted inside by the action of acid just along the surface line of the water. This action was removed entirely by the addition of a little caustic soda to the condensed water; and that water was constantly used as being the purest that could be had for their boilers, in the sense that it contained no solid matter, but simply a little acid, which would be deleterious to the water unless it was corrected by the soda. When he heard of boilers suffering by reason of the action of the oil used in the engine, he felt it ought to be known that there was such a simple mode of correcting this deleterious influence.

The PRESIDENT wished to mention one fact in reference to the boiling of grease in water. He knew a case of a boiler with a surface-evaporator condenser, where the water was used over and over again for a fortnight with very little loss. The boiler then began to leak at the seams, in consequence of the acid grease which formed on the plates. This was entirely cured by pumping in hard water; the lime in that water entirely neutralised the grease, turning it into a non-acid grease, and only produced occasional lumps of insoluble soap, which were perfectly innocuous. On the same principle Price's Candle Company converted ordinary neutral grease into acid grease, by extracting the glycerine from it by means of continued boiling at *very high pressure*, according to Tilghman's process. He had no doubt that the special trouble which had been experienced with the boilers under discussion was partly due to a higher pressure than usual being employed, as the neutral grease was much more quickly and thoroughly decomposed at such pressure, than at ordinary pressures. With regard to the case of Mr. Hughes in Paris, he believed Mr. Browne would give some confirmatory evidence in reference to it. In certain cases the water used in Paris, and elsewhere on the continent, was of such a nature, that the scale it formed upon the tubes took up the grease very greedily, and then it would become a sort of greasy stone.

Then the water would not touch the tubes, and the high temperature of 600° which Mr. Adamson had spoken of was necessary to decompose or drive off the greasy deposit. As soon as this had happened, the tubes, being at almost the highest evaporating temperature, flashed a great quantity of water into steam, which no doubt tended to strain the tubes and the boiler. It therefore seemed a mass of evidence was being obtained, which all tended to a clear explanation of the action going on in the boiler. In reference to what Mr. Peacock had said about tallow, he thought if much tallow got into a boiler, there would then be a quantity of grease which would boil to an acid grease; but if only ½ lb. of tallow was used to 100 miles, and the water was changed nine times, it could scarcely affect the boiler.

Mr. B. C. BROWNE said in reply that the first point to which Mr. Hughes had called attention was the working at such high pressures. Of course he quite admitted that to have an explosion, or even a bursting of a tube in the street, with a pressure of 220 lbs., would be a very unfortunate thing; but at the same time in an ordinary locomotive, working at 150 lbs., if a tube were to burst or anything of the sort happened, it would be a very serious affair; and the additional pressure from that to 200 or 220 lbs. he did not think would make the matter very much worse. It must also be considered that a very much smaller boiler could be used with the higher pressure. The greatest possible amount of care and supervision could be exercised over the manufacture, and it could be made of the very best material. So far the boilers of Brown's engines had been made of steel carefully selected. The tubes were also of steel, or of homogeneous iron; and no more difficulty had been found in keeping them tight, either from the shape or the amount of pressure, than in other locomotive boilers. With regard to the question of joining the horizontal cylinder to the vertical, the way in which it was done was this. The hole was first cut in the larger or vertical cylinder, and the plate was flanged outwards on an easy curve: the horizontal cylinder was also flanged outwards, and the two were then laid on each other. Care was taken to see that they actually took a good

bearing of metal to metal all over, and then he believed they made an excellent joint. In the drawing all the stays were not shown. The rule for the staying of a boiler of that sort was much the same as the rules that would be used for the staying of any other boiler to be worked at high pressure.

With regard to the question of dust and dirt injuring the engine, Mr. Hughes had quoted the case of an express engine; but an express engine was raised a great deal higher than a tramway engine. It was true it went faster, but it ran on raised rails, which were always practically clean and dry. On the other hand, the tramway-road was almost like a ditch, into which everything flowed, not only water but mud; and with the small wheels there was far more opportunity for the dirt to get into the mechanism. He wished they had had some further expression of opinion on that point; but certainly, wherever he had seen a design for a tramway engine, great provision was made for keeping the dust and dirt off the machinery.

With regard to the condenser, Mr. Hughes thought it was insufficient for the work it had to do. In fact however they succeeded in showing very little steam, usually none at all. He believed that the condenser would practically condense all the steam when the engine was running; which was quite a different thing from the amount it would condense if the engine was at rest, because of the cold air constantly passing over it when running. The weight of the condenser was about 400 lbs.; it was all made of exceedingly light copper tubes, and it had 230 sq. ft. of surface. Theoretically he believed there was sufficient surface to condense two-thirds of all the steam that was used under ordinary circumstances. But of course when there were no horses in sight, or other objection, the drivers would perhaps throw off a little steam. On the whole Mr. Brown had certainly succeeded in preventing all complaints as to steam showing; and, after all, he believed that all engineers, in their heart of hearts, looked on the condenser as a mistake, and as entirely useless. They used it because people had the feeling that steam would frighten horses and perhaps be objectionable by going into the windows of houses; but they all looked forward to the time when tramway engines would be more used, and when they would be able to work

without condensers in England, as was done in other countries. the meantime, whatever satisfied the Board of Trade and the pub ought to be sufficiently good to satisfy engineers.

The shape of the boiler had been objected to by Mr. Adams He himself thought that after all the practical reply was that boilers did not give any trouble. At Hamburg, after trying engines for a year and a half, the police had just brought regulations sanctioning the use of Brown's engine, and of no other least without special experiments. The engines there and elsewh were quite out of Mr. Brown's hands, and belonged to the differ Tramway Companies, just as locomotives were the property Railway Companies.

With regard to fuel consumption, he quite expected that so observation would be made upon the Table at page 51 with refere to Strasburg. It certainly looked at first sight rather startling see the consumption rise from 20 lbs. in August to 30·50 lbs. November, while at the same time the number of miles was less. thought that was chiefly owing to two causes. In the first pl tramway engines would always use more fuel, and obviously m oil, in cold weather, when the oil was always clogging, than t would in hot weather, when the oil was liquid. Secondly, w engines making less mileage, there was more standing time and m cooling down than before, and the consumption per mile would higher. It would be remembered also that 1878–9 was an unusu severe season. The winter came on early, and the engines then to fight their way through the snow that was constantly falling; t he believed, entirely accounted for the extra consumption. At page the average consumption of coke was given as 5¾ lbs. per mile. page 55 it was stated that on level roads (Strasburg of cou was not a case of level roads), and with a certain wei and speed, they could work with a consumption of 3·6 lbs. per m A letter received by his firm on 5th November, from the mana of the Strasburg Tramways, stated, "We use now on an aver 3 lbs. of coal per kilometre;" which was 4·8 lbs. per mile, or roug speaking about half-way between what was used in 1878, what was spoken of as the consumption under practically per

circumstances: and, taking into account the difference between the Strasburg road and a dead level, that proportion was about what it should be. At Hamburg the consumption was much higher, but that was gas coke.

Mr. Schönheyder had found fault with the square link at the end of the piston rod. He admitted that it was not a perfect construction, and where the conditions were suitable they introduced a small connecting-rod. But it had one great advantage, namely that if it wore loose it could be so easily lined up, and adjusted to the greatest nicety.

With regard to the fact of one man working this engine, while there were necessarily two men on a railway engine, members should bear in mind the great ease with which a man could stop a tramway engine. Not only this engine, but almost all tramway engines could be stopped in something like their own length under ordinary circumstances. If a man suspected anything therefore, he could stop the engine at once. The engine was stopped, as it was, at all sorts of places and under all sorts of circumstances; it was a very small affair to halt at once if the driver suspected that anything was wrong. At the same time he did not remember ever hearing of a man having to stop his engine on account of want of steam, or for anything of that sort.

With regard to what happened with the Brown engines in Paris, he was sorry to say that he could only give exceedingly imperfect information. The engines in Paris were not made at Mr. Brown's works, though they were made on his principle. They were in the hands of other people, and therefore he could not speak with such accuracy on the point as he could wish.* But he could show that elsewhere the engines had been so successfully worked that people bought them in large numbers and came back again and again, and ordered more, which after all proved that they were a commercial success. Even if all the stories related with regard to the engines

* Mr. Browne has since informed the Secretary that these engines have worked on the 'Etoile' line, regularly and without cessation, for nearly two years. Their number has been increased to 17, and they are now the property of the Tramway Company.

in Paris were true, he did not think they would affect the ques
because of course the best engine might be spoiled, if it were
used properly, or if it were put upon a sufficiently bad road.

With regard to Mr. Crompton's remarks, he knew that
gentleman was not fond of using a condenser at all, and he hi
quite agreed with him. Mr. Crompton said that a tramway en
ought to be produced for something like £300, and that this en
had probably cost £700 or £800. As a matter of fact however
cost nothing like such a sum. But what he supposed Mr. Crom
really meant was that tramway engines would not succeed until
could be made for something like half their present cost; in c
words, that half the amount of work and complications in exis
engines must be swept away. Looking at the engine described,
Mr. Hughes's engine, or any other, he thought they might pr
nearly see their way to that. First of all, they were now sacrifici
great deal to make the engines as light as possible. In many ca
if they did not regard weight, they could use more cast iron &c.,
so make the engine a great deal cheaper. The condenser, the clo
in of the sides, and several other parts, were really put to sat
people outside, more than for any real work the engine had to
At present they never knew what road they would have to go u
or what load they would have to draw; but if they simply ha
deal with one or two tram-cars, loaded full of people, on a fairly g
road, and if they had got rid of all those outside consideration
was the case on railways, there was no doubt that tram eng
could be made enormously cheaper than they were now.

Some observations had been made on the tramway itself.
believed very few, even of those tramways that had never had
engine on them, were fit for anything. He had had to look at
tramway question, not only as an engineer, but also as a t
councillor; and it appeared to him that, whatever system had b
adopted, almost all roads were made far too light, not so much
the tramway work, as for the other work that came upon them.
almost all manufacturing towns, weights went through the str
amounting to as much as 10 tons on one wheel; he him
frequently sent out loads of machinery on wagons in excess even

that. But those heavily loaded vehicles, once crossing over a tramway, might so injure it as to make it very awkward for either cars or engines passing over it afterwards.

With regard to the coning of the wheels, Mr. Brown had started by having an exceedingly small amount of coning, and now he had all his wheels absolutely parallel.

With regard to the question of oil getting into the boiler, he believed it was a matter of circumstances. It might be found that in certain places it was possible to mix up the condensed steam and the feed water without injury; but certainly it was safer, where it was practicable, to keep them separate from each other. In Paris and elsewhere a calcareous soap was certainly formed from the water and grease combined, exactly as had been stated by the President.

The PRESIDENT proposed a vote of thanks to Mr. Browne for his paper, which was unanimously passed.

The Meeting was then adjourned till the following day.

The Adjourned Meeting of the Institution was held at the Institution of Civil Engineers, London, on Friday, 23rd January, 1880, at Three o'clock, p.m.; EDWARD A. COWPER, Esq., President, in the chair.

The following paper was read :—

ON IMPROVEMENTS IN MACHINERY FOR ROLLING IRON AND STEEL PLATES.

BY MR. EDWARD HUTCHINSON, OF DARLINGTON.

Before proceeding to describe the nature of the proposed improvements, it will be well to notice briefly the method generally adopted at present in Rolling Plates, as compared with that in use for producing flat bars, angles, or other sections.

Those latter forms of manufactured iron are produced by means of rolls with several grooves, of gradually decreasing sectional area, cut on their surfaces, so that generally two, and sometimes three pairs of rolls are required to contain the number of grooves or spaces necessary. Thus the production of large sections of angle, tee, channel iron &c., is very expensive on account of the first cost of the rolls, in cases where the section is an unusual one, and the quantity of lengths required is not large. On the other hand, as the bar is rolled to its exact section, and in forming the pile no allowance need be made for waste in shearing (except so much as is necessary to ensure a clean end to the bar), the cost per ton rapidly diminishes with the increase in quantity produced.

Thus, of all forms of rolled iron, double-headed rails are the cheapest; then follow the commoner sections of bars, angle-iron &c. used in shipbuilding and elsewhere; whilst the most expensive forms of all are the heavier sections of channel and joist iron, the cost of which is augmented not only by the ordinary difficulties attending their manufacture, but also, and perhaps to a still greater degree by the smallness of the quantity required at one time.

With plates another state of things exists, and totally different conditions have to be taken into account, in estimating the cost of any given specification. Here the cost of the rolls is not to be considered, nor is the quantity required at one time of much importance. The chief point affecting the cost of production

(supposing the specification to require only plates of ordinary length, breadth, and thickness) is the variable proportion of waste in rolling plates of different widths and lengths, due to the fact that plates are not rolled, like bars, to their exact dimensions, but between plain rolls, and therefore a certain width must be sheared off each side, as well as off the ends.

In the trade a bar is supposed not to exceed 8 or 9 in. in width. All widths above this are taken as plates, unless specially ordered as bars; but most large bar-mills now roll bars up to about 12 in. wide if required. Bars above this latter width become very expensive, chiefly on account of the number of rolls which would be required for intermediate widths, as well as the great number of sections of puddled bar which it would be necessary to provide. All above 12 in. wide, and many under, are therefore rolled as plates, and sheared on the sides as well as the ends. The process may be described as follows. A pile is made of puddled bar and of scrap, the latter composed of the shearings off finished plates. The puddled bars are generally from 12 to 18 in. wide, the width being regulated to some extent by that of the finished plate intended to be produced. After being heated, the rough pile is first put through blooming rolls, to close the edges, and to compress and solidify the mass. It is then usually turned sideways to the rolls, and put through the roughing rolls as many times as are necessary to bring it up to the required width, allowing a margin for shearing, and for inaccuracies as to straightness &c.; it is then turned again and gradually elongated, partly in the roughing and partly in the finishing rolls, until brought down to the required gauge, regardless of its length.

In order to ensure a perfect plate, it is necessary to allow for shearing at least 3 in. on each side, in a strip of fair length; so that for a 12-in. plate more than 30 per cent. of the rough strip is cut to waste on the edges alone. In other words, whereas a pile of 6 cwt. would be heavy enough to make a *bar* of a given weight, 12 in. wide, a 9-cwt. pile would be required to produce a sheared *plate* of the same dimensions. With plates at £8 per ton, and scrap iron at £3 per ton, this extra waste would amount to a clear expenditure of 50s., per ton of finished iron, in waste of materials alone.

This difference of course decreases as the width of the ba
plate increases; because the proportion which the allowance
waste bears to the whole mass becomes less and less the wide
plate. In all cases however a very liberal allowance must be r
to ensure a sound edge; notwithstanding which there is ir
plate mills a very great loss due to the proportion of plates w
owing to defective edges, will not cut to the full size required.

In steel, the difference in value between the finished plate
the scrap is of course greater than in iron; and the resulting lo
more serious in the like proportion.

In order to overcome these objections to the prevailing meth
rolling plates, at least as regards *narrow* plates, the mill know
the "Universal Mill" was devised. It has also been called
Belgian mill, from its frequent adoption in Belgium. In this cou
it has not been generally successful, owing chiefly, it is believe
the objection English workmen have to novel appliances, or ra
perhaps to the difficulties which manufacturers in this cou
experience in adopting labour-saving machinery. The writer how
has had an opportunity of judging of its merits during several mo
fair work at the Britannia Works at Middlesbrough.

The construction of the Belgian mill is not in a strict sense
complicated nature. When however we consider the great stre
required for every part of this class of machinery, the rough us
and the enormous cost of break-downs and delay, we shall
that there are certainly a greater number of parts requiring ca
adjustment about the Belgian mill than is consistent with
highest economy in production; in other words, if bars could
rolled of the same widths in ordinary rolls as in the Belgian r
the latter could not compete with the former in point of economy.

As shown in Plate 4, the Belgian mill is simply an ordi
mill with a pair of vertical rolls A A behind the horizontal ones
The former catch the plate as it leaves the horizontal rolls,
compress the edges sufficiently to close and solidify them.
surfaces of the vertical rolls move a little faster than those of
horizontal rolls.

In practice it is not found desirable to compress the edges much more than is just about sufficient to preserve the width, without decreasing it; and the piles are generally made about the same width as the finished plate is intended to be. This implies the necessity for great diversity of width in the puddled bars, a difficulty which is usually got over in Belgium by using several narrow bars of variable width, to form the tops and bottoms of the piles. Thus from a stock composed of 5, 6, 7, and 8 in. puddled bars, piles of all widths above 10 in. could be built up, rising by inches. It is however impossible to admit that a plate so made, *i.e.* with a welded instead of a solid surface, can be so sound, or so uniform in tensile strength across the grain, as one produced in the ordinary way.

Most Belgian mills, probably with a view to avoid expensive complications, consist of only one pair of horizontal rolls working in combination with vertical rolls; and these are usually in connection with an ordinary plate mill. This prohibits a large production, as the rolls become too hot if the work is continuous.

The manipulation of the Belgian mill is by no means a simple matter, nor can it be placed in the hands of inexperienced or unskilful workmen. The slightest maladjustment of the screws, either of the vertical or of the horizontal rolls, will cause the plate to twist; whilst, if the vertical rolls are allowed to exercise any undue pressure on the edge, it becomes thickened to such a degree, that the plate is sure to curve more or less the next time it is passed through the rolls; and any attempt to straighten it afterwards is generally useless.

Under any circumstances the action of the vertical rolls is to a certain degree objectionable. The pressure, however slight, has a tendency to open the edge; and the thickening, which it is always difficult to avoid entirely, is for many purposes a serious drawback; for instance, where a number of plates of uniform width are placed in juxtaposition, as in the flange of a large girder.

The difficulty of keeping the plates straight, and the impracticability of afterwards straightening them, as already mentioned, will always be an objection of greater or less importance to the general adoption of the Belgian mill. To these may be added its great expense, as

well in first cost as in maintenance. Perhaps however the most important point in its disfavour, especially for rolling steel, is the limit to the width of plate that can be produced by it. If the horizontal rolls are 6 ft. 6 in. long, and the verticals 2 ft. in diameter, 2 ft. 6 in. would be the limiting width of plate for such a mill; since the vertical rolls when opened to such an extent come in contact with the standards. This was the limit at the Britannia Works; and plates were rolled there 32 ft. long, by 2 ft. 6 in. wide, by $\frac{3}{8}$ in. thick, with perfectly sound and straight edges. No greater difficulty seems to attend the manufacture of wide than that of narrow plates, except a tendency to buckle when the plate is very wide and thin.

In the plan, Fig. 2, Plate 4, are shown housings or standards made of a form which permits the vertical rolls to separate so far, that a plate with close straight edges could be rolled almost as wide as the length of the horizontal rolls. But it is clear that such an arrangement would still further compromise that simplicity which it is so desirable to maintain in machinery of this kind; besides which, the guides carrying the vertical rolls, owing to their increased length, would have to be of extremely massive proportions; as indeed would every part of such a mill.

The tendency already mentioned in wide thin plates, to buckle, or bend up, between the vertical rolls, would require to be obviated, in plates much over 2 ft. wide, by some special contrivance. This has not yet been worked out, so far as the writer is aware; and, although it is obvious that such an appliance could be devised, this complication would add very materially to the objections which already exist.

The advantages of the Belgian mill may thus be said to be confined to large establishments, where more than one plate mill is in constant operation, and where plates under about 2 ft. 6 in. in width may always be selected from the orders in hand, in quantity sufficient for one mill. Under such circumstances a very considerable saving may be effected. Whether or not the plan could be profitably applied to all classes of work, is a problem which could be solved only at very considerable expense.

In Fig. 3, Plate 5, is shown the general construction of a Sliding Roll mill, designed to accomplish the same object as the Belgian mill, without being open to any of the more serious objections against the use of the latter. The construction of this mill may be thus described. The ordinary rolls of a plate mill are removed, and in the same standards a pair are substituted of the form shown in the drawing. It will be seen that the top roll A and the bottom roll B are nearly alike in form: and that a collar D is placed on the top roll A, and a collar C on the bottom roll B. These collars are not cast solid on the rolls, but are capable of sliding along them; being held however in one position longitudinally, as regards the other roll, by corresponding grooves.

Applied to the end of the top roll A is a powerful screw E, which takes its thrust from the top chock F, and consequently rises or falls as the top roll is adjusted in height. By working this screw a longitudinal traverse is given to the top roll A, its necks being of such a form as to allow of this motion; whilst the bottom roll B remains firmly fixed endways between the standards. The end motion of the top roll A carries with it the bottom collar C, whilst the top collar D remains stationary; and by this means the distance apart of the two collars is adjusted ad libitum, being limited only by the travel allowed to the top roll A in the direction of its length.

In Fig. 4 is shown the form of box and spindle which has been adopted, and which has been found to present no inconvenience. The rolls are adjusted vertically in the usual way, but clearly they must not be allowed to open so far apart as to draw the collars out of the grooves.

As this system of rolling is applicable to every stage of the process—forge rolling, blooming, roughing down, and finishing—and to steel from the ingot as well as to iron from the pile, it will be necessary to describe it in connection with each of these separately, as it will be found that there are certain points in each requiring special consideration.

Firstly, as to Forge rolling (Fig. 3, Plate 5). It is at all times inconvenient to use very wide piles, owing to their not heating uniformly, and on account of the space and height required in the

furnace, to allow of their being turned: hence it will probably found that rolls arranged to roll puddled bars varying in wi from 12 to 24 in. will meet all requirements. The collars grooves would have to be of such a size as to allow of a verti adjustment of about 5 in. Such a mill would be an extrem simple affair, and need not be further described; but its use wo be attended with great advantage in connection with all plate mi whether the puddled bars were to be afterwards used in mills of same construction or not. The same may be said as regards mi rolling large sections of bar iron, since the same pair of rolls wo produce bars of any width within the length of the rolls, obviat the necessity for frequent change of rolls.

Secondly, with regard to Blooming (Figs. 5 and 6, Plate In some mills this operation could be advantageously combi with roughing down, and both operations done in the same ro the latter process being in fact but a continuation of the form Where large plates were made however, this would be fo impracticable, as sufficient vertical adjustment in the top roll co not be obtained in one pair of rolls without cutting very d grooves, and so leaving the rolls dangerously weak. It is theref necessary to have blooming rolls with a vertical adjustment, ordinary mills, of about 5 in.; so that, taking a pile 12 in. de they would squeeze it down at once to 10 in., and then by success adjustments of the rolls to a minimum thickness of 7 in., at wh the roughing rolls are calculated to deal with it.

Thirdly, as to Roughing down (Figs. 7 and 8, Plate 6). This already stated is simply a continuation of the blooming process. must be remarked however that provision has only been made puddled bars up to 2 ft. wide, and perhaps even this is somewhat excess of what could be used, with due regard to economy of hei and space in the heating furnace: hence all plates above width would have to be rolled with their length in the direct of the width of the pile. There is no objection whatever to t and it is frequently practised for convenience' sake in ordin plate rolling. In these cases the length of the pile would corresp as nearly as may be, with the width of the plate.

Fourthly, as to Finishing rolls. These are generally similar to the above, but are made with still smaller collars than the roughing-down rolls, the adjustment necessary being extremely limited, say from 1 in. to ¼ in. It will be seen that it is impracticable to provide for more than a limited length of travel for the top roll in any case, but more especially is this true of the finishing rolls, where the pressure in rolling is greatest; otherwise the rolls would become dangerously small in diameter in proportion to their length. In practice it will probably be found that a travel of about 2 ft. will be as much as is convenient. So that beginning at 12 in. width, one pair of rolls would finish up to 3 ft. and all intermediate widths. Another pair would begin at 3 ft., and with a travel of 2 ft. would finish up to 5 ft., covering all intermediate widths. Where two mills were in constant operation, the one could be kept on the narrower and the other on the wider plates; but where only one was in use, the rolls would have to be changed occasionally, probably not more frequently than once a week.

The relative merits of this system of rolling as compared with those of the Belgian mill may be briefly noticed. It will at once be remarked that no real side compression can be given to the pile when rolled in this way. In practice however this cannot be effected even with the vertical rolls in the Belgian mill; nor is such compression necessary or desirable, as the pressure of the main rolls is quite sufficient to squeeze the piece out laterally to such an extent as to make it fill the space between the collars in the one case, and between the vertical rolls in the other, and so form a close sound edge. But whilst in the Belgian mill the plate is subjected first to vertical pressure by the main rolls, and afterwards to lateral pressure by the vertical rolls, in the sliding-roll mill the lateral and vertical pressures are simultaneous; and consequently no thickening of the edges or other similar imperfection is possible.

In the Belgian mill the pile must invariably be put into the rolls endwise, because its width would be too little to bridge the distance between the horizontal and the vertical rolls; so that every pile must be made as wide as the plate to be rolled from it. This is a

great difficulty when the plate is over 18 in. wide, and, so far a writer is aware, has yet to be overcome.

The collared roll is also much more readily adjusted to width are the vertical rolls of the Belgian mill. In the latter case not the vertical rolls themselves, but also the plate-guides, both b and behind the main rolls, have to be adjusted with the gre nicety. This causes considerable loss of time and waste of fuel material, as after every re-adjustment one or two experimental p have to be rolled to test its accuracy.

The difference between the two mills in point of first cost hardly be pointed out. The sliding-roll mill does not gr exceed, either in first cost or working expenses, a mill constru on the present model; whilst a Belgian mill would cost a twice as much.

Lastly, the rolling of steel plates by means of the machi described will obviously present no difficulties. This point already been alluded to; but inasmuch as rolling iron from a p a much more complex operation than rolling steel from a solid i the former process has received for the present the most atten more perhaps than its declining importance deserves. Steel plates sooner or later be used, to the very general exclusion of the inf material; and it is confidently believed that the adoption of process described would go far to lessen the great differen present existing between the cost of making steel plates and higher cost of making iron plates of equal weight.

Discussion.

The President was sorry to say that Mr. Hutchinson was ill and was therefore not able to be present; but it had been found impossible to postpone the paper any further, as it had already been postponed from a previous meeting.

Mr. Jeremiah Head said that the author of the paper was well known in the North of England as a very ingenious and sound mechanic, and of great experience in rolling-mill machinery; therefore anything that came from him deserved their very closest attention. It had often puzzled himself how it was that no English manufacturer seemed to be able to compete with the Belgians in what were called "broad flats," or even to make them at all. A large number of those broad flats, or plates, up to 40 ft. in length and 20 in. in width, had come into the London market, and had been used principally in making builders' girders. There was no English manufacturer, he believed, who had even attempted to make them, except the Skerne Iron Co., when Mr. Hutchinson was their managing director. It was quite obvious that there must be a great saving in rolling these strips as bars, instead of as plates; and it became a question why English manufacturers did not adopt the Belgian method. Some of the reasons for this Mr. Hutchinson had pointed out in his paper: for instance, the specifications were generally for comparatively small quantities to each different width, so that they required frequent changes of rolls, and thus the cost was enhanced; and again there was a great tendency to thickened edges in plates so rolled. The long strips used to make up the top or bottom member of a girder were generally required to be placed one over another; and it was obviously a great disadvantage if there was any thickening at the edges, because, when several thicknesses were riveted together, the rivets were apt to squeeze into the spaces between the plates. Again, a large number of wasters might easily be produced in rolling such plates, owing to their tendency to curve sideways, and to

the extreme difficulty of straightening them afterwards. It was known perhaps to every one that, in rolling broad and thin secti the extension of the iron all took place in the direction of rolling, the grip of the two rolls upon the surface almost enti preventing any extension sideways. It was therefore clear th pile of iron, when put into the rolls, must be about the same w as the broad flat intended to be produced; therefore a large nun of piles of different widths must be made to suit the diffe specifications. The Belgians had overcome that difficulty by hav a succession of widths of puddle-bars, as detailed in the paper; this involved side-welds at the top and bottom, which were objectionable, tending to produce what was known as "reediness, a tendency to split longitudinally into shreds like a reed. remembered not long since seeing some Belgian girders on a t in London, riveted up and ready for the builders, on which he c trace incipient cracks lengthways in several places. No doubt t cracks would be hidden in the walls where the girders rested, therefore would not be of much consequence to the builders; bu anything like bridge work such defects would be quite inadmissi

A system had been devised by Mr. Hutchinson, which intended to supersede the Belgian mill in rolling these broad f and he thought it was a decided improvement. If the flats rolled as bars, it was much better that they should be sque against collars, than between a pair of rolls tending to thicken edges. If broad flats were to be made at all in the Belgian wa was a manifest advantage to make the puddled bars of the fini width, to form the top and bottom of the piles, and not to build t up, as the Belgians did. Mr. Hutchinson therefore wisely decid have his blooming mill and also his puddle-bar mill adjustabl order to make tops and bottoms of the same width as the finis mill; and he himself did not see why the principle should no extended to the making of puddle-bars or the blooming of generally, whether they were to be used afterwards in a similar or in an ordinary plate-mill.

But Mr. Hutchinson would go further than that: he would his plate mills altogether of the new design, to roll plates

2 ft. 6 in. to 5 ft. wide. There he himself could hardly follow him. Most plates that were broader than 1 ft. wide were intended to have rows of rivets along the edges. Now it was of vital importance that along a row of rivets the iron should not be "reedy," and therefore should not in its manufacture have been always spread in one direction only. In an ordinary plate-mill the plate was not extended always in one direction; the pile was generally put through sideways until it was rolled out to the full width, and then it was turned at right angles, and rolled out to the required length. Also in entering the hot slab, the men found it easier to themselves to work forward one corner till the rolls caught it, and next time to advance the opposite corner. In that way the grain of the iron in the finished plate was continually being varied in direction; it became eventually more or less crossed or interlaced. The result was that a seam of rivets was never in the exact line in which the grain of the iron ran. He thought that was a very important point, especially in boiler plates, where seam rips were produced more easily if the iron was in any sense reedy. But if all plates were made by the system described in the paper, he feared there would be a great tendency to reediness.

Again, if plates were to be made on that system of all widths, the mill would be a very cumbrous one. It would consist of a blooming mill, of two pairs of pinions for conveying the motion to the top rolls, and (if it went to 6 ft. or 6 ft. 6 in. widths) of three sets of finishing rolls. No doubt in small mills rolling bar iron there might be several sets of rolls without inconvenience; but with ponderous plate-rolls it was desirable that there should not be too many attached to one mill.

It was very curious to notice the effect of rolling on the tenacity of iron, and also on its elasticity in bending. It was well known that the tensile strength of good iron plates was something like 22 tons per sq. in. in the direction of the grain, and only 18 tons across. He had heard it stated that in steel plates the difference did not exist; but from the experiments he had made he believed it did exist, though not to the same extent. Iron was not only stronger along the grain, but it would bend round to a much greater angle, both cold and hot,

than it would across the grain. As far as he had experimented, h had found that mild steel plates also bent rather better in th direction of the grain than they did across it. It was curious tha extending the iron should at the same time increase its tenacity He could only account for it on the supposition that the molecules (iron were thereby forced into closer contact one with another, so tha they came more completely within the range of attraction (cohesion.

He was inclined to agree with Mr. Hutchinson that there was better chance of using his method for wide steel plates than for iron because the steel plates were made either from ingots, which were ca pretty square, or from blooms made from ingots, which wei hammered square beforehand; therefore there was a better chance (a good edge to start with. He might also add that reediness was liability attaching rather to iron plates, when badly manufacture than to steel plates, which, if not good, were untrustworthy in oth ways. Mr. Hutchinson based his claim for saving in great part on tl avoidance of the scrap produced by shearing plates; but it mu be borne in mind that iron plates could not be made without son scrap. If, by the adoption of Mr. Hutchinson's method, there we little or no scrap produced in plate mills, he did not know ho the higher qualities of plate iron would be made at all. The scr obtained from shearing plates was put into the pile, and, beii double worked, it was very useful, especially for producing th higher qualities. The paper however was a very valuable one, aı not the least of its merits was the extreme clearness with which M Hutchinson had expressed his views.

Mr. F. W. WEBB would confine his remarks to the rolling steel. Up to the present time all steel ingots were found to l honeycombed to a greater or less extent, especially on the outsid and especially if cast in iron moulds. Now in rolling steel plat for boiler purposes he had always endeavoured to make the ingots such a size—not less than 2 ft. square—as that, when the ingot ha been compressed and rolled into a plate, the cells on the two fac might be flattened out to mere thicknesses of paper, while those (

the edges were cut away in the scrap. If he were to edge the ingot by putting it into a pair of Mr. Hutchinson's blooming rolls, he should experience the difficulty that the honeycombs on the two edges would be merely closed up, but not disposed of. In making large plates he always made it a practice to hammer the ingot on the two faces only, and let all the little cells on the edges develop themselves and burst open, so that they could not by any means be rolled into the body of the plate. To the adoption of that course he believed was due a great deal of the success of the steel plates made at Crewe, and the good results they were giving in wear. Plates made in that way for one of the company's ships, the *Isabella*,—which was now just out of the graving dock, after being at sea for twelve months—did not show any of the defects, or the pitting, said to have been experienced by some persons in the use of steel plates.

There were one or two points to be noticed in the author's system. Every time the collared rolls were turned down, new collars must be put on, or else a series of collars must be kept of different diameters, to fit the rolls each time they were turned down. Again, in rolling finished plates, supposing there was a large order of one width, they would be likely to wear the rolls down, so as to make it necessary for these to be turned before they could make good work of another width. He should also like to know whether the author had had any experience as to unequal heating with these rolls. It was known that, if a roller liked, he could break his roll at any time, by heating it up unequally; and he was afraid lest some difficulty on that score might develop itself with these collared rolls.

Mr. DANIEL ADAMSON looked at the mill, from a mechanical point of view, as possessing many excellences; but he agreed with Mr. Head that it was much better adapted to rolling steel plates than iron plates. Iron plates, filled as they were with a considerable amount of cinder, could not be rolled without leaving rough and serrated edges; and if these were closed up by the side action of the collars, the strength in a lateral direction would be far inferior to what it ought to be. Iron that contained a large amount of cinder lost its transverse strength nearly in proportion to the square of the percentage of cinder

contained. Thus iron like Low Moor, which only contained about 1
cent. of cinder, must necessarily have a far higher transverse stre
than the common iron, such as was known in the trade as ship p
or bridge iron, containing not less than $3\frac{1}{2}$ or 4 per cent. of cind
weight; and it should be borne in mind that the specific gravit
the metal was three times that of the cinder, so that the bulk o
latter would be 10 or 12 per cent. When iron was used for struc
purposes, whether for ships, boilers, or bridges, its ultimate stre
might be seriously affected by the question whether there was
or less cinder at a given point. If there happened to be a pat
cinder, which had been drawn out in rolling, so that there w
streak of cinder in a longitudinal direction, this might easily
away half the strength of the plate, when strained in a lateral direc
at a given point. So that the subject was not a mechanical one
but should be looked at from every point of view, so as to l
exactly what the material was composed of. He was inclined to t
that a plate containing $3\frac{1}{2}$ per cent. of cinder lost at least 15 per
of its strength in a lateral direction, while a plate containing onl
per cent. of cinder did not lose more than 4 or 5 per cent.; it
therefore be evident that there was no dependence to be placed
mere mechanical view of the subject. It must thus be clear
it would not answer to apply this system to iron containing
cinder, and intended for bridge purposes; because they had just
clear evidence that not only was longitudinal strength wanted
strength in the transverse direction also, to prevent the occurren
catastrophes such as had lately occurred. The proper applic
of the system would be to roll only the best iron, from which
cinder had been previously expelled.

With regard to steel, if this was serrated at the edge, or foli
on account of the small blow holes at the surface, produce
surface porosities, it would be a mistake to treat it as Mr. Hutchi
proposed; but when large quantities of mild steel plates were r
they were usually found to come out with a rounded, clear, sm
edge, not indicating any of the characteristics of the mixed comp
called plate iron, or even of the harder metal called tool or hard
steel. This latter was much harder than the ordinary ingot steel

when rolled had much the same serrated appearance on the edges as plate iron. He could not at all agree with Mr. Head that with steel plates there was any material difference in the power of endurance, when tested longitudinally and transversely. In a vast number of such experiments, which he had conducted, he had not found a greater variation than 2 per cent. in either direction; and it had as often been in favour of the transverse as of the longitudinal direction. As to bending, he had bent at least 50,000 specimens in a transverse direction, with at least as satisfactory results as he had ever obtained by bending in a longitudinal direction.

The PRESIDENT asked if Mr. Adamson had ever made a chemical analysis of the shearings from the edges of plate, to see if they contained more cinder than the body of the plate.

MR. ADAMSON said he had only referred at present to iron and steel from a mechanical point of view. If an iron plate had a $\frac{5}{8}$-in. hole drilled or punched close to the edge and then drifted out, it would only stretch, as a rule, about $\frac{1}{16}$ in. in diameter. A $\frac{5}{8}$-in. hole drilled in the same position in a mild steel plate would drift out to 80 per cent. increase of diameter. But when a washer was cut out from the iron plate and annealed, then, instead of stretching $\frac{1}{16}$ in. only, it would stretch $\frac{3}{16}$ in. or $\frac{1}{4}$ in. He attributed that to the strip between the hole and the edge of the plate having a tendency to split away from the rest, as the drift enlarged the hole. In the longitudinal direction the atoms, in the process of rolling, became interlocked, as he would explain it in preference to the explanation given by Mr. Head. But by the same longitudinal extension there was often laid down alongside the atoms, when the iron was dirty, a corresponding streak of cinder, which had a tendency to make the strip split out with very great facility; and hence the occasional treacherousness of moderately good iron—good, that is, in its natural composition, but bad in its manufacture. The results, when such plates were used for steam boilers, were seam rents in the direction in which the plates had been rolled.

He thought it was a great misfortune that there was not more evidence before engineers as to the strength of an ordinary flat rolled bar taken transversely, compared with its strength taken longitudinally. There was a fair amount of evidence as to plates in ordinary use; but for bridge purposes, where transverse and lateral strength was required in flat bars, there was, in his opinion, no practical evidence as to their lateral power of resistance. He had no hesitation in saying that iron might lose two-thirds of its strength in the transverse direction, through the interposition of a non-metallic component; and if so, it was obvious how dangerous it was to depend much upon a flat bar when strained in a transverse direction.

The PRESIDENT said that the occurrence of cracks in Belgian iron lengthways, owing to the want of perfect welding between the several bars of the pile, was a circumstance noticed before, by himself and by others. One point to be considered about the system in question was, whether the iron would keep out of the grooves and collars, or would get into them, when they were worn a little; but the practical experience of Mr. Hutchinson would no doubt put that matter to rest.

With regard to what Mr. Head had said about the interlacing or interlocking of the fibres in rolled iron, it seemed to him that, when iron first came to nature in the furnace, it was all in little pieces, so to speak. These little pieces were more or less perfectly welded together in the rolling; but each particular piece was elongated to very many times its original length, and so became a thread or fibre. Those fibres lying alongside of one another, and more or less perfectly welded, produced toughness in the longitudinal direction of the plate, but only in that direction, if it were continued to be rolled lengthways. Hence the necessity of handing the plate round, and rolling it sideways, or cornerways, as well as lengthways. That advantage would, he thought, be very much lost in rolling large plates on the plan described, unless they were first rolled crossways to get the width; but so long as the metal was good enough and clean enough, a raw edge would not be made. The collars, he

thought, were sufficient to keep the metal together, the same as in rolling ordinary narrow bars; but all engineers knew that wide plates had a great tendency to form ragged edges, and the natural feeling was that it would be better to cut those off. He begged to propose a vote of thanks to Mr. Hutchinson for his paper, which was very clearly written, and very well illustrated by drawings.

The vote of thanks was passed.

The following paper was then read :—

IS AUTOMATIC ACTION NECESSARY OR DESIRABLE IN A CONTINUOUS RAILWAY BRAKE?

BY MR. T. HURRY RICHES, OF CARDIFF.

In bringing the above problem before the members of this Institution, the writer is actuated only by a desire to see the subject thoroughly discussed, as being one which deserves the careful consideration of the Board of Trade, the railway companies, and the general public, before any definite instructions are issued by the Board of Trade upon the momentous question of the Continuous Railway Brake to be finally adopted throughout the kingdom. In the first place it appears necessary to point out that there exists a difference between the ideal automatic brake, as conceived and understood by the public, and the actual automatic brake found in regular use upon a few of the railways of this and other countries. The former, as all know, should anything go wrong with any of its many vital parts, indicates the fact with certainty, or else at once applies itself to the wheels: whilst the latter has a very heavy list recorded against it of failures to fulfil either of these desirable objects; and in addition shows a very large number of instances where the brake was rendered entirely useless for the remainder of the journey (frequently a long one) owing to its getting out of repair. As more detailed particulars are furnished further on regarding these different classes of failures, the writer refrains from dealing with them here. He will now define what appear to him to be the essential points upon which to base the opinion, whether or not any of the known automatic brakes are sufficiently reliable to justify their adoption in preference to non-automatic brakes. These points are as follows.

(I.) A comparison should be made between the number of recorded accidents in which automatic action has either prevented or mitigated disaster, or else which might have been beneficially affected if automatic brakes had been fitted to the trains, and the number of accidents and failures which are recorded as caused by defects in parts necessary to make the brake automatic. The greater number of these latter mishaps have rendered the brake useless until the train could be taken to the repairing shed; hence in many cases the trains had to be run for the remainder of the day without a continuous brake available to meet emergencies.

(II.) As the danger of trains separating has been held to be one of the most pressing reasons for requiring automatic action in railway brakes, the writer has carefully searched the Board of Trade Returns for the year 1878, and has also written on the subject to a large number of locomotive superintendents in this country, in order to ascertain as far as possible the number of cases where trains have parted, either with or without collision. He finds only three cases of the kind reported in the Board of Trade Returns during the whole year. Of these the first occurred to a passenger train which left the rails at a junction, the carriages taking both roads: in that case the Government Inspector reported that if the train had been fitted with any description of continuous brake, the driver could have pulled up in time to avoid the accident. The second case was where a train was fitted with an automatic brake; and this brake suddenly applied itself to the hinder portion of the train, and pulled it up, breaking the train in two. The third instance was where a train, fitted with an automatic brake, was running at a speed of 45 miles per hour, when one of the tender wheels broke away, and falling beneath the train smashed each brake cylinder as it passed over it, entirely disabling the brake. The train travelled about 300 yards after leaving the track, and was finally stopped and broken up into sections by coming in contact with the abutment of a bridge, which it reached at an estimated speed of 25 miles per hour. These constitute the whole number of recorded instances where couplings were broken, and where automatic action could display itself; and it will be noticed that in one the breaking was caused by automatic action, and in another the

automatic action was useless; therefore in only one, and that a very questionable instance, could an automatic have been of any more use than a non-automatic brake. It should further be noted that in each case severance did not occur until the carriages had been running off the road for some distance, and until the main damage was done; in other words it did not occur until the brake, if available, ought to have completed its work. Finally, as a contra account, we find in the same Returns the details of more than twenty instances of failure, by defects occurring to the various *extra* fittings, necessary to make the brake work automatically; and in many of these instances the brake was rendered inoperative, thus leaving the train to be worked all the way home with the ordinary hand-brakes only. Hence the comparison under this heading, so far as the Board of Trade Returns for 1878 are concerned, stands thus:—one questionable success as against twenty failures.

The private enquiries made by the writer as to the experienc of the various gentlemen to whom he applied, have brought to ligh only two or three cases of a train parting; all of which appea to have occurred at or near stations, and to have been caused b an injudicious use of hand or automatic brakes: the fact being i each case that the engine brakes were held tight on just at th moment of coming to a stop, without an equal brake power bein applied to the rear of the train, and that the sudden recoil of th buffers caused the breakage of the couplings. But if the engin brake is gently released at the moment of the stop, or the rear brak gently applied, this violent action will never take place; and with an continuous brake whatever, capable of easy regulation, it can b avoided without difficulty. Strong couplings should in all cases b the sufficient safe-guard against all breaking loose of trains fro whatever cause.

On the other hand it may be shown that every automatic brake h at least double the number of parts that a non-automatic brake has therefore there is double the risk of failure from parts getting out order, as well as a much greater risk of improper use by the me who have to work and handle the brakes. Further, many of t

working parts of an automatic brake are necessarily complicated and delicate in construction; and hence are more liable in themselves to get out of order.

In order to get a general view of the whole working of automatic brakes during the eighteen months ending June 1879, the writer has compiled, from the Board of Trade Returns on Continuous Brakes, the appended Tables I–IV., which give the total number of failures recorded against the following automatic brakes—the Westinghouse, the Sanders or Sanders and Bolitho, and the Steel McInnes. For comparison with these the non-automatic Smith Vacuum Brake has been selected, and the failures of that brake are also shown. These failures are throughout distributed under several headings, according to what appear to have been the circumstances of each particular case. An examination of these Tables will amply bear out the remark just made, as to the larger number of failures in working parts with automatic as compared with non-automatic brakes.

(III.) The next point for consideration is the number of cases where, through defect in automatic apparatus, brakes creep on whilst the train is running, and finally stop it, often at most objectionable places. Among special instances may be mentioned that of the Blaenmoor tunnel, where a Midland train was pulled up in this way; also the accident at Wemyss Bay, when a following train ran into the one automatically stopped, and injured thirteen persons. But besides these there are, as column (7) of the Tables shows, a number of instances where this automatic stoppage has taken place, and has been, to say the least, most inconvenient. It must be further considered that this large class of stoppages is without any countervailing advantage whatever; and that this process of creeping on whilst running has a strong tendency to heat and injure tyres, and also to induce an immense waste of fuel.

(IV.) Where trains are worked down long inclines, none of the existing automatic brakes work as efficiently as the non-automatic, because the former cannot be so easily and nicely regulated as the latter. This fact is mentioned in M. E. Marié's Report upon the two descriptions of brakes in use on the Lyons Railway, where he

says "The Westinghouse brake is so difficult to moderate that it could not be employed on long inclines or steep gradients." This objection applies to every description of automatic brake.

On summarising the Tables I. II. and III., which give the failures recorded in the Board of Trade Returns for the half years ending June 1878, December 1878, and June 1879 respectively, the writer finds, as shown in columns (6) and (12) of Table IV., that the total number of instances in which the several automatic brakes were rendered useless through failure amounts collectively to 83, for a recorded mileage (that for the two last half-years only being returned) of 2,900,435½ miles; whilst with a similar mileage of 8,338,481 miles the non-automatic brake named has only 21 instances where it was rendered useless, including the two cases of broken couplings notified in the June half of 1879. Thus, assuming that the relative mileage in the first half-year was the same as in the other two, the absolute failures in proportion to mileage, with the automatic and non-automatic brakes, are about as eleven to one. This fact appears especially adapted to indicate the relative value of the two descriptions of brakes, looked at from the point of view of their forming a reliable apparatus, capable of working a train with safety throughout a journey.

Next to this comes the question of liability to mismanagement on the part of the men who have to use the brakes, and also of those who have to couple and uncouple them. Here it appears from column (3), Table IV., that with the automatic brakes the failures recorded as due to mismanagement were 88, and with the non-automatic brake 27; which, taking the relative mileage into account, gives a ratio of about nine to one.

Next comes the question of reliability as a train-stopper. Here it will be found from column (10), Table IV., that the result, for equal mileage, is three to one in favour of the non-automatic brake: the total number of cases of overrunning stations &c. with the Smith brake being 22, and with the automatic brakes 27.

Again, if the total recorded failures are taken, the automatic brakes will be found, from column (11), Table IV., to give collectively

[redacted]

447 cases, and the Smith brake 264: giving a result, for equal mileage, of about five to one. This should be a guide as to the amount of care required in maintaining the two descriptions of brake.

We have next, in column (7), Table IV., the cases where automatic brakes apply themselves and stop trains. This has occurred as many as 39 times; and in one of these instances the train was pulled up in the Blaenmoor tunnel, very much to the alarm and annoyance of the passengers.

Next comes, in column (8), Table IV., the record of cases where chain-couplings have been broken by the action of the automatic brakes. Of these there are few.

Then comes, in column (9), Table IV., a list of 81 cases where the automatic brakes would not release when required, until some particular part or defect was attended to: under this class of objectionable incidents must be included the Wemyss Bay accident, when thirteen persons were more or less injured.

In concluding his paper, the writer has only to call attention to the several tabular lists given, and the comparisons to be drawn from each. These, he thinks, furnish very strong reasons for the opinion held by him, that there is not as yet any automatic brake at work in England, sufficiently reliable to justify its use in preference to the best descriptions of non-automatic brakes. For example, as the Board of Trade impress upon railway companies the necessity of keeping punctual time, the fact that automatic brakes have in a large number of instances delayed trains, through failure in the automatic arrangements themselves, forms one strong objection to their use. Again, automatic action is required by the Board of Trade to guard against damage when trains part asunder. But automatic action has itself caused fully half the number of such accidents: hence it seems hardly worth while to use an appliance which doubles the number of these rare cases of breaking loose.

The writer has not noticed the Clark chain-brake, as it appears to be used more as an emergency brake than otherwise. He has also endeavoured to avoid criticising any particular brake, having only the desire to call attention to what appear to him substantial

objections to all the automatic brakes which have come into any
like extensive use upon the railways of this country; and in thi
to bring on a thorough discussion as to the desirability of ado
automatic brakes in general. Such a discussion, he believes
develop substantial grounds for insisting on further improve
and experiment, before any stringent measure in this directi
enforced upon railway companies. It appears absolutely nece
that any automatic brake which is to be regarded as satisfa
should be less complicated than any now in use; and to effect
improvement, yet further thought must be applied to the pro
and yet further experience acquired to achieve its solution.

TABLE I.—WORKING OF BRAKES FOR SIX MONTHS ENDING JUNE 1878.

(1) Name of Brake.	(2) Name of Railway.	(3) Fault of Men.	(4) Fault of Automatic attachments.	(5) Fault of ordinary material	(6) No of times Brake was rendered useless.	(7) No of times Brake applied itself	(8) No of Couplings broken by brakes.	(9) No of times Brake refused to release	(10) No of times Train overran stations.	(11) Total number of recorded Failures	(12) (13) (14) Mileage run.	(15) List of Stock fitted with Brake. No of Engines fitted.	(16) No. of Carriages fitted.
Westinghouse (Automatic)	Great Eastern	1	—	—	1	—	—	—	—	1	No mileage given in the return for this half-year. Therefore, to show a comparison, a list of stock fitted with each brake named is given in columns (15) and (16).		
,,	Great Northern	—	3	11	5	1	1	1	—	15			
,,	London, Chatham & Dover	—	2	6	3	2	—	1	—	8			
,,	Midland	—	2	3	1	—	—	—	3	5			
,,	North Eastern	2	2	2	1	2	—	2	—	5			
,,	Glasgow & South Western	—	—	1	1	—	—	—	—	1			
,,	Totals	3	9	23	12	5	1	4	3	35		145	722
Sanders (Automatic)	Great Western	—	9	3	12	1	—	—	—	12			
	Midland	1	—	2	—	—	—	—	3	3			
,,	Totals	1	9	5	12	1	—	—	3	15		25	82
Steel (Automatic)	Caledonian	No account given of any failures to any brakes.										2	13
Smith (Non-Automatic)	Great Northern	—	—	18	2	—	—	—	—	18			
	Great Western	—	—	2	2	—	—	—	—	2			
	Lancashire & Yorkshire	1	—	—	—	—	—	—	—	1			
,,	Midland	1	—	—	—	—	—	—	—	1			
,,	North Eastern	—	—	5	1	—	—	—	—	5			
,,	Glasgow & South Western	—	—	1	—	—	—	—	—	1			
,,	G. S. & W. of Ireland	—	—	4	—	—	—	—	—	4			
,,	Totals	2	—	30	5	—	—	—	—	32		426	1882

N.B.—In every instance failures of "brake rigging" are included.

TABLE II.—WORKING OF BRAKES FOR SIX MONTHS ENDING DECEMBER 1878.

(1) Name of Brake.	(2) Name of Railway.	(3) Fault of Men.	(4) Fault of Automatic attachments.	(5) Fault of ordinary material	(6) No. of times Brake was rendered useless.	(7) No. of times Brake applied itself.	(8) No. of Couplings broken by brakes.	(9) No. of times Brake refused to release.	(10) No. of times Train overran stations.	(11) Total number of recorded Failures	(12) Total Mileage run by each Brake.	(13) Mileage run for each time the Brake was rendered useless.	(14) Mileage run for each Failure recorded.
Westinghouse (Automatic)	Great Eastern . . .	1	—	—	—	—	—	—	—	1	76,459		76,459
	Great Northern . . .	—	14	4	—	—	—	11	—	18	23,895		1,327
,,	London Chatham & Dover	1	1	5	3	5	—	2	2	8	57,408	19,136	7,176
,,	Midland	1	3	2	—	—	—	—	2	5	300,268		60,053
,,	North Eastern . . .	1	6	9	5	1	—	8	1	18	137,826	27,565	7,657
,,	Caledonian	—	—	4	3	3	—	4	—	7	62,441	20,813	8,920
,,	Glasgow & South Western	—	1	—	—	—	—	—	1	1	133,763		133,763
,,	North British . . .	1	—	11	1	4	—	—	—	13	156,023	156,023	12,001
,,	Totals and Averages .	5	25	35	12	13	—	25	6	71	948,083	79,007	13,353
Sanders (Automatic)	Great Western . . .	—	3	5	5	1	—	—	—	5	92,254	18,450	18,450
	Midland	1	—	4	1	—	—	—	4	6	97,980	97,980	16,330
,,	Totals and Averages .	1	3	9	6	1	—	—	4	11	190,234	31,705	17,294
Steel	Caledonian	—	—	3	—	—	—	3	—	3	20,856		6,952

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Smith (Non-Automatic)	Great Eastern . . .	—	—	4	1	—	—	—	—	5	340,771	340,771	68,154
	Great Northern . . .	5	—	18	—	—	—	—	—	23	1,253,204		54,487
	Great Western . . .	—	—	—	—	—	—	—	—	0	19,141		
,,	Lancashire & Yorkshire.	—	—	5	—	—	—	—	—	5	Not given.		
,,	London Chatham & Dover	—	—	—	—	—	—	—	—	0	9,664		
,,	Manch. Sheff. & Linc. .	2	—	3	2	—	—	—	3	5	547,033	273,816	109,526
,,	M., S. Jn., & Altrincham	3	—	5	—	—	—	—	—	8	87,609		10,951
,,	Metropolitan	1	—	2	—	—	—	—	—	2	560,783		280,366
,,	Midland	2	—	—	—	—	—	—	—	2	175,690		87,845
,,	North Eastern . . .	—	—	26	—	—	—	—	2	26	234,806		9,031
,,	South Eastern . . .	—	—	—	—	—	—	—	—	0	116,150		
,,	Taff Vale	1	—	1	—	—	—	—	2	2	56,332		28,166
,,	Glasgow & South Western	—	—	2	1	—	—	—	1	2	19,261	19,261	9,630
,,	Great Northern of Ireland	—	—	1	1	—	—	—	—	1	35,482	35,482	35,482
,,	Great Southern and Western of Ireland .	—	—	13	—	—	—	—	7	13	474,697		36,515
,,	Midland G. W. of Ireland	—	—	—	—	—	—	—	—	0	26,212		
,,	Totals and Averages .	14	—	80	5	—	—	—	15	94	3,957,385	791,477	42,100

N.B.—In every instance failures of "brake rigging" are included.

TABLE III.—Working of Brakes for Six Months ending June 1879.

(1) Name of Brake.	(2) Name of Railway.	(3) Fault of Men.	(4) Fault of Automatic attachments.	(5) Fault of ordinary material	(6) No. of times Brake was rendered useless.	(7) No. of times Brake applied itself.	(8) No. of Couplings broken by brakes.	(9) No. of times Brake refused to release.	(10) No. of times Train overran stations.	(11) Total number of recorded Failures	(12) Total Mileage run by each Brake.	(13) Mileage run for each time the Brake was rendered useless.	(14) Mileage run for each Failure recorded.
Westinghouse (Automatic)	Great Eastern	6	12	1	—	2	—	14	—	19	74,998		3,947
	Great Northern	—	—	4	2	—	—	—	—	4	22,272	11,136	5,568
,,	London & Brighton . .	41	48	27	—	1	2	—	3	82	245,372		2,992
,,	London Chatham & Dover	1	6	6	10	6	—	—	—	12	49,557	4,955	4,129
,,	Midland	9	22	56	10	3	—	16	3	84	248,531	24,853	2,958
,,	North Eastern . . .	3	3	3	—	—	—	1	1	6	168,809½		28,134
,,	West Lancashire. . .	—	—	—	—	—	—	—	—	—	27,620		
,,	Caledonian	—	1	8	3	1	—	6	—	9	80,052	26,684	8,894
,,	Glasgow & South Western	—	—	1	—	—	—	—	—	1	181,837		181,837
,,	Glasgow & Bothwell .	—	1	—	—	—	—	—	—	1	66,187		66,187
,,	North British . . .	10	3	5	—	5	—	5	—	17	389,103		22,888
,,	Totals and Averages .	70	91	113	25	18	2	42	7	235	1,503,838½	60,153	6,399

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Sanders (Automatic)	Great Western . . .	3	—	12	11	—	—	1	—	15	101,068	9,187	6,787
	Midland	4	6	49	4	—	—	5	4	59	113,102	28,275	1,917
,,	Totals and Averages .	7	6	61	15	—	—	6	4	74	214,165	14,277	2,894
Steel (Automatic)	Caledonian	1	—	2	1	1	—	1	—	3	23,259	23,259	7,753
Smith (Non-Automatic)	Cheshire Lines . . .	—	—	1	—	—	—	—	—	1	156,260		156,260
	Great Eastern . . .	1	—	12	1	—	—	—	4	13	326,316	326,316	25,101
	Great Northern . . .	6	—	41	1	—	—	—	—	47	1,470,039	1,470,039	31,277
,,	Great Western . . .	—	—	5	4	—	—	—	—	5	84,395	21,098	16,879
,,	London Chatham & Dover	—	—	4	—	—	—	—	—	4	19,586		4,896
,,	Manch. Sheff. & Linc. .	—	—	9	—	—	—	—	—	9	273,221		30,357
,,	M., S. Jn., & Altrincham	—	—	9	—	—	—	—	—	9	86,666		9,629
,,	Metropolitan	4	—	3	—	—	—	—	—	7	554,668		79,238
,,	Midland	—	—	14	2	—	—	—	1	14	173,910	86,955	12,422
,,	North Eastern . . .	—	—	23	3	—	—	—	2	23	252,473	84,157	10,977
,,	South Eastern . . .	—	—	—	—	—	—	—	—	—	114,578		
,,	Taff Vale	—	—	—	—	—	—	—	—	—	72,097		
,,	Great Northern of Ireland	—	—	—	—	—	—	—	—	—	35,030		
,,	G. S. & W. of Ireland .	—	—	4	—	—	—	—	—	4	676,849		169,212
,,	Midland G. W. of Ireland	—	—	2	—	—	—	—	—	2	85,008		42,504
,,	Totals and Averages .	11	—	127	11	—	—	—	7	138	4,381,096	398,281	31,747

N.B.—In every instance failures of "brake rigging" are included.

TABLE IV.—Summary of Tables I., II., III.; and List of Stock fitted with each Brake.

(1) Name of Brake.	(2) Half-year ending.	(3) Fault of Men.	(4) Fault of Automatic attachments.	(5) Fault of ordinary material and apparatus.	(6) Number of times the Brake was rendered useless.	(7) Number of times the Brake applied itself.	(8) Number of Couplings broken by action of brake.	(9) Number of times Brake refused to release after having been once applied.	(10) Number of times Trains overran stations, &c.	(11) Total number of recorded Failures.	(12) Total Mileage run by each Brake.	(13) Mileage run for each time the Brake was rendered useless.	(14) Mileage run for each Failure recorded.	(15) Total Engine stock fitted with Brake.	(16) Total Carriage stock fitted with Brake.
Westinghouse (Automatic)	June, 1878	3	9	23	12	5	1	4	3	35	Not given	Not given	Not given	145	722
"	December, 1878	5	25	35	12	13	—	25	6	71	948,083	79,007	13,353	197	1017
"	June, 1879	70	91	113	25	18	2	42	7	235	1,503,838½	60,153	6,399	226	1426
	Totals and Averages	78	125	171	49	36	3	71	16	341	—	69,580	9,876	—	—
Sanders (Automatic)	June, 1878	1	9	5	12	1	—	—	3	15	Not given	Not given	Not given	25	82
"	December, 1878	1	3	9	6	1	—	—	4	11	190,234	31,705	17,294	58	175
"	June, 1879	7	6	61	15	—	—	6	4	74	214,165	14,277	2,894	86	287
	Totals and Averages	9	18	75	33	2	—	6	11	100	—	22,991	10,094	—	—
Steel (Automatic)	June, 1878			No	recorded		failures.				—	—	—	2	13
"	December, 1878	—	—	3	—	—	—	3	—	3	20,856	—	6,952	2	13
"	June, 1879	1	—	2	1	1	—	1	—	3	23,259	23,259	7,753	4	33
	Totals and Averages	1	—	5	1	1	—	4	—	6	—	—	7,352	—	—
Smith	June, 1878	2	—	30	5	—	—	—	—	32	Not given	Not given	Not given	426	1692

Discussion.

Mr. R. D. SANDERS observed that the appended Tables I.-IV. were stated to give the total number of failures recorded against the following automatic brakes—the Westinghouse, the Sanders or Sanders and Bolitho, and the Steel McInnes: and the author added up all the failures shown with those three brakes, and compared the joint result with the Smith vacuum brake. He did not think that was fair to the individual brakes; nor was it quite a scientific way of opening up the subject of automatic action. If they were to discuss the automatic action of brakes, or the necessity for it, he thought it might be done scientifically, without referring to any individual brakes at all.

In the Tables a great number of failures of various classes were put down, but it appeared to him that the most important class of all was left out. In one column was given the number of times each brake was rendered useless, in another the number of times each brake applied itself, and so on; but there was nothing to show the number of times when each brake would *not* apply itself when wanted. He thought this was the most important point to be considered, with reference to automatic action. In speaking before the Institution, he had always enforced the necessity of the automatic action being used as a tell-tale for the brake; but that consideration appeared to be left out of the paper altogether. He did not find from any of the Board of Trade circulars that they insisted on automatic action so much for the purpose of preventing accidents by a train breaking in two, as the author seemed to think. What they said was that "in case of accident the brake must be instantaneously self-acting," which was a very different thing; but at the same time he maintained that automatic action was very useful in case of a train breaking in two. The paper had given one or two instances of this, but had left out some that were within his knowledge. The Wigan accident was an instance in which the engine broke away from the train: the driver, finding he had left the train behind,

stopped his engine, and the consequence was that the following trai ran into it. Then again there was the memorable Shipton accident If there had been an automatic brake on that train, so that th guard could have put it on at the rear, and held tight the coupling of the carriage which was running off the road, it was very doubtfu whether there would have been an accident at all; for it was prove afterwards that the train ran for some considerable distance, after th tyre had broken off the wheel, and it was not until both driver reversed their engines, and so put a block in front of the trai that the accident happened.

Reverting to the question of the tell-tale action of brakes, h found, on referring to the Board of Trade returns, that, with th brake which the author had put forward as so superior to ever other, there were 107 instances where the pipes had been undon or where there had been some defect in the brake, of which th driver could not possibly have had any knowledge; and taking th various non-automatic brakes together, there were 128 instance recorded, where the driver was thus travelling along without an knowledge whatever of the state of his brakes. Any one of thos instances might have led to very serious consequences; therefore h thought they should have been put forward in the Tables.

With regard to the great number of cases where the brake wa rendered useless, it was necessary to point out that in his ow particular case there had been only one instance where the brak had refused to go on when required; therefore it was hardly fair t condemn that brake because, when classed with two others, the join result turned out badly.

In order to prove the value of automatic action he had selecte two instances. On 10th February 1879, a train left St. Pancra fitted up with a non-automatic brake; it travelled all right until it go to Mill Hill, where the signals were against the driver. He attempte to apply his brake, but found he could not get it on at all. Th consequence was that he ran through the station at 40 miles an hou Fortunately there was nothing in the road, otherwise there would hav been an accident. Again, a train fitted with his own brake, whic was an automatic brake on the tell-tale principle, left St. Pancras o

25th November 1878; and the driver immediately after observed that there was no vacuum shown on the gauge in front of him on the engine, and therefore that there was some defect in the brake. He had to stop at Kentish Town, and, knowing that the brake was out of order, he worked carefully up to the station, and stopped with the ordinary tender brake in the usual way. On examining the train, it was found that the valve in the centre van had been left open. When that was put down, the train worked satisfactorily all the way to Liverpool. Those two instances were quite sufficient to show the value of automatic action as a tell-tale. In one case the driver was travelling along under the impression that the brake was all right, when it was not; and this might have led to a serious accident. In the other case the driver saw that his brake was out of order, worked cautiously to his first stopping station, found out the defect, put it right, and went on as usual.

On page 102 the paper said, "On the other hand it may be shown that every automatic brake has at least double the number of parts that a non-automatic brake has; therefore there is double the risk of failure," &c. Now he had made a careful comparison between the Smith vacuum brake (which was the one the author referred to) and his own, taking the same identical carriages. With the ordinary non-automatic vacuum brake there would be these parts,—one sack, two lines of pipes, two branch connections at the ends of the carriages, four hose-pipes and fittings, and four half couplings; in all thirteen principal parts. With his own brake, as he was fitting it up at the present time, there was one cylinder and piston, corresponding with the sack on the other carriage, one reservoir, one line of pipes, two hose-pipes and fittings, and two half couplings; in all seven principal parts, or about one-half the number in the non-automatic brake; therefore the author's statement was wholly incorrect.

On page 103 he found the remark:—"Where trains are worked down long inclines, none of the existing automatic brakes work as efficiently as the non-automatic, because the former cannot be so easily and nicely regulated as the latter." That might be true of some automatic brakes, but not of his own, which could be regulated with as great nicety as the non-automatic vacuum brake. In the

latter case the brake was applied by drawing the air out of a cham
and, in proportion to the air drawn out, so were the blocks pre
against the wheels. In the former case the brake was applie
letting the air into a chamber, and, exactly in proportion as the
was let in, so was the pressure put upon the blocks. The
difference was that the former went on very rapidly, and the l
very slowly; but that was scarcely a point to be made ag
automatic brakes.

On page 105 the paper stated: "We have next, in column
Table IV., the cases where automatic brakes apply themselves
stop trains. This has occurred as many as 39 times." Upon refe
to these Tables he found two cases of his own brake recorded.
admitted that the brake did so apply itself in those two cases.
one case, reference to the Board of Trade returns would show t
connecting pipe between two carriages came undone, and stoppe
train; but when the guard put on a new pipe, the train went aw
usual. In the other, one of the sacks had been cut half way thro
and when the vacuum got rather high it burst. That brake
disconnected, and the train then worked as usual. He contended
was the very thing that *should have happened.* Far better to sto
train when a pipe came undone, and so let everybody know what
the matter, than for a pipe to come undone without giving notice
cause the train to run through a station at 40 miles an hour,
Mill Hill. That really showed the value of automatic action. H
only had these two instances where his own brake applied i
spontaneously, so to speak; and it was not fair to say that, be
there were 39 such instances recorded in the Board of T
returns, therefore automatic action was of no use. Here were
instances which clearly showed the great value of automatic a
in preventing accidents. Another occasion where automatic a
was of great value was shown by a case which occurred at Rea
with his own brake. The driver, on approaching the station, attem
to apply the brake, but could not do so: the valve upon the en
had got out of order, and he failed to get the brakes on at all.
guard noticed, by the gauge in his van, that the driver was not put
the brake on, and was going to run through the station. He l

his own valve, and put it on for him. The consequence was that the train was pulled up at the station all right. If that had been a non-automatic brake, no one could have put it on in such a case, and the train would have run through, as at Mill Hill, and another accident might have been caused.

Again, the paper quoted, as another point against automatic brakes, the way in which they "crept on." All he could say was that he had had no instance of that with his own brake; in fact it was simply impossible. There had been cases where the blocks rubbed against the wheels; but the Board of Trade returns would show that in all those cases the blocks had been too tightly adjusted. The author's concluding remark was, "It appears absolutely necessary that any automatic brake which is to be regarded as satisfactory, should be less complicated than any now in use." With reference to that remark, he had already shown that his own particular brake had only about one half the number of parts that there were in the non-automatic brake; and therefore this conclusion was rather misleading. Finally, he would again impress upon all who studied the safety of the public, the value of automatic action as a *tell-tale;* not so much to provide against the train breaking in two, as always to indicate the working condition of the brakes; and he maintained that in his own particular arrangement this was most effectually carried out. He challenged the writer of the paper to show in what way the power of his (Mr. Sanders') brake could be reduced, or the brake become defective, without the driver and guards knowing all about it; and further how, in any non-automatic brake, a driver or guard was to know when a pipe was undone, or the brake otherwise defective.

Mr. George A. Gutch wished first to draw attention to the question they had met to discuss, which was this:—Is automatic action necessary or desirable in a continuous railway brake? That was a perfectly natural and intelligible enquiry to be made on the part of any gentleman who intended to fit up trains with continuous brakes, and was uncertain as to the principle upon which they should act. But Mr. Riches had left out that question altogether in his paper, and had never attempted to discuss it. He had chosen instead

to take certain brakes, and compare them together as to certain cla
of failures. That was not the right way to treat such a quest
At page 100 the author proposed to "define what appear to him t
the essential points upon which to base the opinion, whether or
any of the known automatic brakes are sufficiently reliable to ju
their adoption in preference to non-automatic brakes." The gro
was thus changed; and very little was really said against the prine
of automatic action. Everything was made to refer to the metl
of carrying out that principle in practice, which were very differe
just as the principle of non-automatic action might be carried ou
some persons in one way, and in quite a different way by others.
could imagine some people, for instance Mr. Fay and Mr. Nev
not being satisfied to accept the brake which Mr. Riches had acce
as a standard of comparison. Mr. Riches must remember that
comparison of failures would cut both ways; for Fay's and New
brakes had no failures recorded against them at all. It was true
they were now obsolete, and did not comply with the conditions of
Board of Trade, but still they were very fair brakes up to a cer
point: neither did the Smith vacuum brake comply with the condit
of the Board of Trade. He wished to point out therefore th
principle should not be condemned, because there had been in s
cases a failure to carry it out successfully.

Again, on page 101, the author recommended that "a compar
should be made between the number of recorded accidents in w
automatic action has either prevented or mitigated disaster, or
which might have been beneficially affected if automatic brakes
been fitted to the trains, and the number of accidents and fail
which are recorded as caused by defects in parts necessary to n
the brake automatic." That was a most extraordinary way
arriving at a conclusion. For if an accident had been prevente
was not recorded at all; failures only were recorded, not succe
Hence there were no figures to work with. According to
principle the better a brake had fulfilled its purpose, by preven
accidents, the worse the comparison that could be made abou
A railway, for instance, might keep clear of accidents altogether
a year, by the aid of a good automatic brake; but if there were

failures of material during that time, the paper would state the case as fifty failures and not a single success. A better comparison could be made by taking the number of failures which would affect the efficiency of the brakes, when wanted to be called into action. With non-automatic brakes such failures were always a source of danger, because, as Mr. Sanders had said, there was no tell-tale; while an automatic brake immediately pointed out that something was the matter, and brought the train to a stand. That he considered to be an enormous advantage, and so apparently did Mr. Riches himself; for on page 100, when making a comparison between the ideal and the actual automatic brake, he said:—"The former, as all know, should anything go wrong with any of its many vital parts, indicates the fact with certainty, or else at once applies itself to the wheels: whilst the latter has a very heavy list recorded against it of failures to fulfil either of these desirable objects." On the other hand, in the Tables at the end of the paper, the number of cases in which this "desirable object" was fulfilled, were ranked as "failures."

With regard to the author's remark on page 105 that "automatic action is required by the Board of Trade to guard against damage when trains part asunder," the words used by the Board of Trade really were, "In case of accident, to be instantaneously self-acting;" therefore they referred to failures or accidents to the brake itself, as well as to the train. Similarly, in the questions to be answered by the railway companies he found, "whether self-acting." Nothing was said about the train parting; and Mr. Riches and others were wrong in believing, that the only reason for laying down that condition was that trains were always breaking in two. There was evidently a wish on the part of the Board of Trade to have a brake which would act as a tell-tale, and would be sure to go on in case of failure of the brake itself. Many accidents happened from failures of tyres, from rails or wheels breaking, and from other causes of derailment; and these could only be provided for by an automatic brake, which should not only go on, but stay on, so that, even when the couplings parted or the engine ran away, the rest of the train should be prevented from running into it.

The breaking in two of a train occurred very seldom, but quite o enough to be provided against, even in ordinary working. The au had said that in looking through the Board of Trade returns the year 1878 he could only find three cases. But railway compa did not in general return *all* the cases of breaking of coupli or drawbars, but only those cases from which accidents resulted, which the Board of Trade had to report upon. There were how more cases actually reported than those mentioned by the author. the summary of accidents, in the Board of Trade return for 1878 found 16 cases of failures of couplings reported, causing in to 7 passengers and 2 railway servants; and no one imagined this was the total of broken couplings or drawbars in that one for the United Kingdom. For instance, the experimental vacu brake train, while preparing for and during the brake trials at in October 1878, broke seven drawbars or couplings, fortuna with no serious results. Moreover the above 16 cases did include an accident at Methley Junction near Leeds, on the Mid Railway, on 13th December 1878, when a collision took between a goods train and the up Scotch express. The latter thrown off the line, and the engine, after running off the line 90 yards, was thrown on its side over an embankment; fortuna out of the way of the train, upon which there was no contin brake. Neither did they include a collision on the Lancashire Yorkshire Railway, on 2nd September 1878, at Kirkgate sta Wakefield; which, according to the Government report, "furnish strong argument in favour of the general adoption of autor brakes." The Bickley accident, which was the third of the instances mentioned by the author as the only cases of coupl parting in that year, was also shown under a different heading, was not included in the 16 cases mentioned above.

But the most curious omission on the part of the author was of the accident on the Great Northern Railway of Ireland, on August 1878, between Skerries and Balbriggan. There a coup broke on the limited mail, and the train, which was fitted the Smith vacuum brake, ran into the engine and tender, inju five persons. Still confining himself to the year 1878, he himself

of various other cases where couplings or drawbars had broken; but as these were not recorded officially, he would refrain from specifying them.

He wished to recur to the Bickley accident, because the paper specially commented on that, calling it a questionable success. Now the Government Inspector, in his report on this accident, said, "the effect of the automatic action of the brakes, coupled with the retarding force exercised by some wheels being off the rails, was, it is estimated, to reduce the speed from 45 to 25 miles per hour, when the leading brake-van struck the abutment of the South Eastern Railway bridge in running a distance of 215 yards." And yet the paper implied that this brake could not have been of more use than a non-automatic brake under those circumstances. But it must be admitted that, if the train had been fitted with a vacuum brake, and the vacuum pipe had been damaged by the broken axle, as the Westinghouse pipe was on that occasion, the brake could never have been applied at all; and even if there had been an opportunity of putting it on during the 215 yards actually run, before the train struck the bridge and the couplings parted, the brake must then at once have come off all the wheels: and with the engine and tender off the line, and the rest of the train running on, that might have been a very serious matter. As it was, it was true that the broken wheel carried away the brake of several carriages as it passed under them; but all those brakes at least remained on until they were carried away, while of those behind them some were found fast on the wheels a considerable time afterwards. It was impossible to assume that such a case as that detracted from the value of the brake. No brake could of course be of service, after it was torn from the carriage by a broken wheel; but up to that time the brake did excellent service, and it was put on automatically by the axle breaking. It was nearly always the case, when an axle broke, that the brake apparatus was the first thing to be damaged. In such cases the driver usually stated in his evidence, "The first that I knew about it was that my brake was on."

He should like to know from Mr. Riches whether, in his opinion, such accidents as this at Bickley were to be provided against or not;

and if they were, whether he himself, being in the train expecting such an accident to happen, would prefer to have u him a brake that would go on automatically as soon as a cou was broken or brake-pipe damaged, and would then stay on whether he would prefer a brake that, even if there had an opportunity of putting it on at first (which in this case ther not, as the main pipe was broken), would automatically have off as soon as the engine parted from the train, as it did on occasion. What sort of condition ought the Board of Trade t down, in order to meet contingencies of that nature, if not the brake must be self-acting? He should like to hear a sugge on that point, but the paper had avoided it altogether.

The great cure for breakage of couplings, according to author, was that the couplings should be strong enough. The to that was that they were not strong enough, because they did b as already shown; also that in an accident a power could be bro to bear sufficient to break any size of coupling or draw-bar, that no strength of coupling would prevent the shackle lifting o hook, as it sometimes did.

As to the Tables, the method of comparison adopted in the was, in his opinion, most faulty. It was evident to any one wh studied the returns of the Board of Trade, and observed the diffe in the returns from different lines, that the railway companies ha various interpretations upon the directions of the Board of Tra to what information they were to supply. Again, it was unfa compare an automatic brake, which recorded its own failures, another brake which, when out of order, failed to record the He objected to the term "failures" with regard to instance which automatic brakes put themselves on, because such inst were really successes of the principle of the brake; they were failures of the material, or of the individuals using it. It coul be called the failure of a principle, where a brake in failing sto a train, and warned the driver; nor could that be compared wi case where there was a failure of material, and the train was all to run on without its being known. The two things were ent dissimilar. To blame an automatic brake for going on when a

accidentally burst, was just as reasonable as to blame an automatic signal for going to danger when the wire broke; or to blame the block system, because some mistaken signalman chose to let two trains pass into the same section together, the system being intended to keep them apart.

He believed the author was quite mistaken in saying, as he did more than once, that a great many automatic brakes had been rendered useless, until the train could be taken to the repairing shed. He must have been deceived in his deductions, because he could only have got his information from the Board of Trade returns, and by judging of the failures. He did not know whether Mr. Riches had tried any other brake than the Smith vacuum brake: certainly he had not tried the Westinghouse brake, or else he could not have made that remark. He had himself made a comparison between the Westinghouse automatic brake and Smith vacuum brake, and had found altogether 123 reports against the Smith brake, and 233 against the Westinghouse; but there was a very different tone about the reports against the two brakes. The reports on the Westinghouse brake, he noticed, referred mainly to trifling delays from some easily preventible cause, *e.g.* "Some one tampered with the cocks"—"Engine not fitted"—"Shunter opened cock in guard's van"—"Guard accidentally opened his valve with sleeve"—"Copper pipe broken"—"New washer wanted"—and also other trifles which had nothing to do with the individual brake, and were common to every brake. In the reports against the vacuum brake these trifles seemed to be generally omitted, and the failures reported consisted largely of couplings coming undone, and sacks being found slit.

Looking at the results all round, he found that they were very much against the vacuum brake. The total number of failures in the half year ending June 1879 was 123, of which 79 (or 64 per cent.) were really dangerous failures, that might have produced serious consequences by materially affecting the stopping power of the train as a whole. In the Westinghouse brake, on the contrary, only 8 out of 233, or 3½ per cent., could in any sense be called dangerous failures. The cases in which the train, as a whole, was prevented from using the brake for the rest of the journey, were

36, or 29 per cent. of the total number, with the vacuum, and 2
only 10 per cent., with the Westinghouse brake. Taking
half year ending Dec. 1878, the reports were very much worse fo
vacuum brake; for out of 89 failures 85, or 95 per cent.,
dangerous failures.

However, as he had said, it was not clear how far the diff
companies made their returns on the same basis. Ther
he thought it was better to take a single railway using
brakes. He would take the North Eastern, because the minut
of their returns, as made to the Board of Trade, wa
indication of the care exercised by the authorities. It was a
line which he knew pretty well himself, and could speak upon
some authority. They returned, for the half year ending June 1
27 engines and tenders, and 35 carriages, fitted with the va
brake, or 89 sets in all; and 15 engines, 18 tenders, and
carriages, fitted with the Westinghouse, or 141 sets in all, 5
cent. above the vacuum. The vacuum brake ran 252,473 n
almost wholly with through trains, having very few stoppages
there were 23 failures reported: 16 of these, or 70 per cent.,
dangerous failures, *i.e.* cases of running through stations, or
which would have had that effect if not found out, such as sli
sacks, couplings coming apart, and so on. The Westinghouse b
ran 168,809 miles, almost wholly with stopping trains, so tha
opportunities of declaring itself out of order, or of runnin
stations, would be much more frequent than with the vacuum b
yet only 6 failures were reported, only one of which could
interfered with the stopping power of the train; and that
caused by a cock being left closed. As those cocks were now
away with, that could not happen again. Of the other
4 occurred in nine days, with a new train just started, and
due no doubt to having new work, and inexperienced drivers. H
if there were nine or ten trains, running altogether 168,809 n
and if two of them had only six mishaps of any kind in six mo
while the remaining seven or eight had not a single misha
maintained this showed that the automatic brake could be w
as satisfactorily as any other piece of machinery. With rega

the miles run per failure, they were 10,977 with the vacuum, and 31,458 with the Westinghouse brake; although there was 56 per cent more stock fitted with the latter than with the former.

With regard to the "creeping on," already referred to by Mr. Sanders, that term was very much more applicable to the vacuum than to the Westinghouse brake. The Westinghouse did not act by creeping on; it could indeed be made to go on very gently by the manipulation of the driver; for the late improvement of the triple valve enabled it to be put on with 5, 10, 20, 30, or 40 lbs. pressure, according to the action of the driver. But the author seemed to infer that in the cases he had mentioned the brakes crept on. In reality the pipes broke, and the brake then went on like lightning, and pulled up the train. Here he would no doubt be confronted with the Wemyss Bay case. The author had done his best to make capital out of that, pointing out that there were some people injured by a following train running into the train that was pulled up. It was true there were people injured, but the reason was that the following train was permitted to enter a block section in which a train was standing. Now what had that to do with automatic action? It was simply a case of a mistaken signalman, on a foggy morning, allowing a train to run into a section where another train had been brought to a stand—a thing which might have happened through a dozen different causes. The block system was precisely intended to protect a train from another following; but the latter ought also to be fitted with continuous brakes. That was not so in the case in question, and therefore the people were injured. In point of fact, the failure was in a piece of the machinery which the Westinghouse Brake Company did not supply, a brass nut, which affected the power of the brake, and brought the train to a stand. The inspector of the Board of Trade enquired into the matter, and his report said, "The accident was therefore clearly due to carelessness on the part of the signalman in Port Glasgow cabin, who disregarded the rules for the working of the block telegraph instruments, and also a rule specially issued."

As to cases of blocks being found tight upon wheels, they from the brakes not having been taken off at the previous stop from their creeping on one after another; they went on all tog if at all. It might happen however, from want of care in handling or supervision, that one or two of the brakes might have come off at the previous stop; but if the driver wa experienced man that never happened. His proof of this was on very many lines the complaint was never made at all. On Great Northern, the Lancashire and Yorkshire, the London South Western, the London Chatham and Dover, the North East the West Lancashire, the Glasgow and South Western, the Glas and Coatbridge, and the North British, there were no cases at mentioned of brakes refusing to come off, or creeping on; and might be done on one line might be done on all.

The paper had also said that down long inclines the autom brakes did not work as efficiently as the non-automatic brake. own experience however was that they could be worked quit easily. In some of their experiments a uniform speed of 27 m was maintained down a gradient of 1 in 55 for five miles, as pr by diagrams that were taken at the time. The paper implied th vacuum brake was admirable for going down inclines. He sh have thought himself that, if a brake showing 79 serious fail out of 123 was dangerous at all, it was especially dangerous going down an incline. But there was also such a thing an ascending gradient; and in the Great Western returns to Board of Trade, this explanation was given with regard to working of the Smith brake on the Monmouthshire line—" of the passenger trains on the Monmouthshire line has two or vehicles at the tail end fitted with Fay's brake, which is used controlling and stopping the train in ascending the inclines; or return journey, down the inclines, Smith's vacuum brake is throughout the train. Smith's brake is not used on the ascen journey except in cases of emergency." It appeared therefore the vacuum brake was not thought to be a very good one ascending inclines, the danger of a break-away, involved by employment of that brake, being too great to be risked.

The paper had alluded to a Report by M. Marié, as to the difficulty of moderating the Westinghouse brake on steep gradients. But M. Marié had not himself tried it on inclines at the time he wrote that report; he had since seen reason, it was believed, to change his opinion. Moreover, that quotation should not have been made without adding the sentence that followed it, which was as follows:—"The vacuum non-automatic brake is dangerous in case of a rupture of couplings, because it does not stop the detached portion." And again, under the heading of "Ruptures of Couplings," the Report said, "In cases of sudden application of the brake the shocks we have just mentioned often cause ruptures of couplings. In the Westinghouse, which is automatic, the rear portion of the train stops of itself; but it is then necessary to provide against the new danger, resulting from a section of the train being suddenly stopped, and remaining stationary on the main line. As for the vacuum brake, which is non-automatic, the severed portions continue running, which presents serious dangers upon inclines." So that M. Marié agreed that the vacuum was not a fit brake for inclines.

Again, the same Report also said on the subject of automatic action:—"It appears that, in general, a certain importance is attached to the fact that, in case of derangement of the apparatus or rupture of a coupling, the brakes apply themselves on each vehicle to stop the train, or sections of the train. This condition constitutes what is called 'automaticity.' We think that this property, limited to passenger trains, would be useless with the existing brakes, because ruptures of couplings do not occur with these trains; but, as we shall see hereafter, the use of continuous brakes will probably cause frequent ruptures of couplings, and for that reason automaticity seems to us made necessary by that kind of brake." It was possible that the author had not seen M. Marié's complete Report, as some very incomplete and incorrect translations of that Report had been circulated in this country.

He was prepared to give a large number of instances, compiled from the Board of Trade returns, as to the value of automatic action, showing that it had done excellent service in the saving of life and property. In fine, he did not see why anybody should object to

automatic brakes, any more than to automatic signals, which we used upon all railways, and in which, when a wire broke, th signal went to danger. There was a great similarity between th block system of signalling and automatic brakes, and also a gre similarity between the old system of signalling and non-automat brakes; and the same arguments which had established the bloc system would, he believed, establish automatic brakes also.

Sir HENRY TYLER had great pleasure in making a few remar on this very important subject, and the more so because he believ he might himself be held responsible to some extent for the origin sin—if such it were—of automatic action. During the many yea in which it had been his duty to enquire into railway accidents, l had paid special attention to the question of brakes; and as t different continuous brakes were invented, he had examined the and made experiments with them. Various gentlemen came him from time to time with their inventions: amongst othe Mr. Clark, whose very ingenious chain brake was still runnin he believed, on the London and North Western Railway. Th first thing he said to Mr. Clark, many years ago, was that, be what it ought to be, his brake should not work in sections, b throughout the train, and should be automatic, *i.e.* that it should on of itself when a separation occurred in the train, instead of goi *off*, as it then did, in the event of the chain snapping. Mr. Cla had contrived arrangements to meet this requirement, but the bra was still at work on the London and North Western, as an emergen brake, subject to this serious defect. He had considered the automat principle to be an essential element, because he believed that, continuous brakes came more and more into use, trains would l run at a greater speed up to stopping places, or obstructions, up to the rear of other trains; and any accident that happened, if t brakes failed to act, or were out of order when needed, wou necessarily be more severe than when trains were without continuo brakes. In the same way, when the vacuum brake was first broug to him, he told Mr. Smith that he considered it very ingenio but that in order that it might be safe for general use it ought to l

automatic; and he had previously told Mr. Westinghouse the same thing. He had stuck to that principle from first to last; and all his experience, since the first invention of continuous brakes, had convinced him that principle was right.

The paper under discussion was intended to prove that there was no necessity for automatic action. The way in which that was sought to be proved was very ingenious; and after hearing the paper read, and then listening to what Mr. Sanders had said very properly in reply, he began to think that—if there were so many failures, as Mr. Riches sought to make out, in automatic brakes; and also so many failures, as Mr. Sanders had pointed out, in non-automatic brakes; and if, as he himself could call to mind, there were also a great many failures in the old-fashioned hand-brakes, in consequence of the stripping of the brake-screw or otherwise—it would be easy, following the same line of argument, to write a paper to prove that it was better to work trains without any brakes at all. But the enquiries in the paper, as to accidents of a particular class, had been confined to the year 1878. Now he supposed that nobody had had more experience than himself in looking through reports of accidents, analysing them, and tabulating their general results; and he knew how much might be made of them in one way or another, unless they were looked at impartially, and with a judicial eye. Now it was not wise or fair in a matter of that sort to be guided by the results of one year only, even if those results were accurately ascertained; and he was quite sure that, if he had the opportunity of taking Mr. Riches carefully through the accidents of that year, one by one, the result would be very different from what had been stated in the paper. He had had many years' experience in the working of railways, and had had occasion to go into those matters very closely. He had long since taken the trouble to go through most carefully, for his own information, every report of every investigated accident during several years; and he had drawn up the Table of results given below, which had not been previously published.

TABLE A.—ANALYSIS OF TRAIN ACCIDENTS.

Year.	Total investigated Train Accidents.	CONTINUOUS BRAKES REQUIRED.				Remarks.
		Under control of drivers.	Under control of guards.	With Automatic Action.	Total.	
1870	122	85	4	13	102	
1871	160	102	8	12	122	
1872	238	163	15	10(a)	188	(a) Including K G.E.R., 1 killed, 16
1873	241	147	14	18(b)	179	(b) Including L.N.W.R., 13 kil injured.
1874	168	100	14	12(c)	126	(c) Including G.W.R., 34 kill injured.*
1875	161	92(e)	11	20(d)	123	(d) Including Sc N.B.R., 3 killed, 25 (e Including Bat G.W.R., 2 killed, 8
1876	144	87	9	16(f)	112	(f) Including Lo ton, G.W.R., 2 k injured.
Total	1234	776	75	101	952	
Average of 7 years	176	110·9	10·7	14·4	136	
Per cent.	100	63	6	8	77	

* This accident also showed the need of the two other requirem

This Table showed, for instance, that in 1870, out of a 122 accidents which were investigated by the Board of T accidents proved more or less the necessity for continuou He had gone through each of those 102 cases, to ascer relative number in which it was important that the brake s under the control of the engine driver, or of the guard, many of them pointed especially to the necessity for a action; and he found that there were 85 cases of the first k the second, and 13 of the third. A similar analysis was each of the succeeding years to 1876, and an average was the whole. He thought this Table was the best reply possibly make to the inference in the paper, that in the

on which Mr. Riches had made partial enquiries, sometimes from interested or prejudiced sources, there were certain results which rather showed that brakes would be better without than with automatic action.

Now the necessity for automatic action arose from a variety of considerations. There was, as Mr. Sanders had mentioned, the "tell-tale" consideration, which was one of the most important. It was altogether a wrong principle to employ a continuous brake, which might at any time be out of order without the knowledge of the engine-driver or the guard, and which, when the driver wanted to stop, whilst running perhaps at full speed, or in a case of emergency, might suddenly fail him, and only then show him that there was no stopping power left, just when he most required it. It was desirable, on the contrary, if continuous brakes were to be used, that the guards and the drivers, who had to work them, should be provided with the means of at once detecting when they were out of order, and be enabled to adopt the necessary precautions for the safety of the train. But it was still further desirable that in such cases the brake itself should persistently refuse to go off the wheels, until it had been put right for the journey. A complaint had been made to him the other day respecting a detention of ¼ hour, on a railway where the Westinghouse brake was employed. The train was an important express, and great complaint was made on the subject. When he looked into the matter, he found that a pipe had burst, and the brake had then properly put itself on; and the men in charge, not being as experienced as they might have been, and not knowing how to manage matters, took some time before they found out how to correct the defect. He therefore told the company that this was a good illustration of the very best point about the brake; if the train had proceeded without warning when the brake was out of order, that would have been dangerous; but the brake had insisted on refusing to go off until it was set in order, and that was quite right. That was the true principle of tell-tale action referred to by Mr. Sanders.

The experience of railway working furnished many terrible accidents, arising from cases where one part of a train had become

detached from the other, which Mr. Riches had ignored, and di seem to be aware of. In those cases the safety of life and depended sometimes upon the instantaneous action of the b Two of the most fatal accidents that had occurred in this co were those at Helmshore, on the East Lancashire Railway, a Round Oak, on the Oxford Worcester and Wolverhampton Rai Both of those accidents arose from the fractures of coupling excursion trains, mounting steep gradients and stopping at sta In each of these cases, which were similar to one another, a train started, the hinder part broke away and ran back dow incline, and there was an enormous loss of life. Those were which above all required automatic action in a brake.

As to the regular working of automatic brakes, particularly of Mr. Westinghouse, he had had the opportunity of ru backwards and forwards with it, every day for many months, bet London and Colchester; and he could speak from experience, as to the value of the brake, because he had seen a collision av by it, and also as to its working without any interruption or diffi except such as might be expected from the best piece of machi He had often thought that, if locomotive superintendents h record the number of failures in their engines, and these similarly reported to the Board of Trade and laid before Parlia it would be found that they very much exceeded in numbe failures of brakes in the course of the year. Still it was quite that attention should be directed to the failures in question, that engineers and others should do all they could to pr their occurrence. What had been said however on the questi some of the reported failures being in reality successes exceedingly important, because it had not been suffici distinguished in the Board of Trade returns, which were fa leading to danger, and which were successes, as tending to pr risk. When it was stated that a certain number of failures occurred in a certain year, it ought to be stated which of these have led to disaster, and which were really successes, as showin the brake was not working properly, and must be put in order the train was allowed to proceed.

Mr. R. Price Williams, as an anxious and disinterested watcher of the problem which had been so carefully discussed, ventured to suggest that it was impossible to answer the question asked in the paper from the data that had been given. In Table IV., which was a summary of the preceding Tables, he had been exceedingly puzzled how to get at the prime factor, which should serve as a guide in arriving at the percentage of accidents recorded. He was told by the author that it would not answer to sum up the items of each horizontal line (omitting only, as he naturally should be disposed to do, the number of times when the brake applied itself), in order to get the number given as "Total recorded failures;" but that, for instance, a case which appeared under the heading "Faults of Men" in column (3) might also appear under another heading in column (4). However he gathered roundly, taking the Westinghouse brake, that the number of times the brake applied itself was about 10 per cent. of the total number of failures; which was about the percentage given by Sir Henry Tyler for the accidents that might have been prevented by the use of an automatic brake. Taking the Sanders brake, the number of failures were so few that, when reduced to the form of a percentage, they really constituted no guide at all as to any average results. Taking the Smith vacuum brake, he noticed the rather striking fact, that the number of times when trains overran the station formed a very large percentage of the failures. He found that out of its 264 recorded failures as many as 22, or more than 8 per cent., arose from the very serious and grave fault of over-running stations. In the case of the Sanders brake, the ratio was as much as 11 per cent.; but in the case of the Westinghouse brake it was less than 5 per cent. So far as he was able to analyse cursorily the results given in the Tables, he saw nothing, for his own part, to justify him in coming to the same conclusion as the author, viz. that the automatic system was not deserving of use. On the contrary, in his own experience he had seen accidents similar to those that had been mentioned—one notably with a train on the Buxton and New Mills line, which ran back and broke in two —where, by the simple action of an automatic brake, the train would have been arrested. A full consideration of the great dangers

attending this class of accident had led him to the co
engineers must apply themselves to the problem of n
continuous and automatic.

M. DAVID BANDERALI observed that some of the railv
in France were disposed to accept automatic contrivai
provided they were specially simple and reliable in
He thought the principal objection to automatic ac
France, and also perhaps on some lines in England wher
block system was not in use, was precisely the ten
automatic brake to stop a train in the middle of its j
something went wrong with the fittings. To this a
managers and superintendents of the lines objected v
On his own line, the Northern of France, they had
finding a mode by which the passengers would have
stopping the train; but great objection was made to the
superintendent of the line and the traffic manager, an
was accordingly placed only in the hands of the guard
be just the same, should the brake itself stop the tra
the passenger. He thought this would form a great
the present, on all lines where the block system was n
because in such cases a train stopping in the middle o
was a source of serious danger. If an automatic br
devised, which would only warn the driver that it was
instead of stopping the train, he was sure there would
objection to automatic action than there was now.

Mr. ALEX. MCDONNELL considered there was a grea
said in favour both of automatic and of non-automatic acti
question was, he thought, whether automatic action, as
present, was not being purchased at too great a cost, a
of an amount of complication in the machinery which wa
advantage, on account of the number of accidents that
He thought that Mr. Sanders was somewhat unfair in
parts of his brake. He himself did not exactly under
piston and a cylinder could make up one thing: it see

they were two things, and that by counting in that way all sorts of results might be arrived at. Mr. Sanders commented upon a case at Mill Hill, of a train running through a station at the rate of forty miles an hour, because the brake did not act properly. Certainly the driver must have been very slow about his work, if, from the time he found the brake would not go on, he did not put his hand-brake on, and retard the train to some extent. If the continuous brake became useless, the driver at least was not worse off than if he had no continuous brake at all, and depended upon his hand-brake only. He thought it was also unfair to suggest that the writer of the paper was comparing one favourite brake against three. If he had compared it with a single brake picked out of those three, he would have been taxed with unfairness in making a selection of one bad brake, while the others were exceedingly good.

The question of rating the value of a brake by the number of its failures was one of extreme difficulty. He dared say that many engineers in the same position as himself had had considerable difficulty in deciding exactly what constituted a failure, and whether they ought to report a certain case to the Board of Trade or not. There were some things in the Tables which pointed to that difficulty. Looking at Table III., for the half-year ending June 1879, it would be found that the London and Brighton Company had reported a failure with the Westinghouse brake for every 2992 miles run; but on referring to Table II., it would be found that in the half-year ending December 1878 they had reported no failures at all. He took it for granted that the Brighton Company did not get all their brakes put on in the six months; and there surely must have been some failures in the first half-year, when there was such a vast number in the second. The discrepancy must therefore have arisen from some misconception in the way in which the Brighton Company reported their accidents. For his own part he had had, in one or two cases, very considerable difficulty in making up his mind as to whether accidents should be reported or not. If a brake did not go on, it did not generally cause an accident, and there would be no delay at the station. Again, if a pin came out of a brake block, it was no accident, and it would not cause a delay at the station; the driver simply got

down and put the pin back again. In one case that might be re as a failure, and in another case it might not be reported at a that there was a great deal of difficulty in the matter.

With respect to many of these failures, particularly connected with the brake gearing, he believed they were often by a very rough use of the brake by the drivers. Unfortu rapid stoppages had too often been considered the one an test of the excellence of a brake; and therefore enginemen h into the habit of bringing their trains to a stop much more q than was needful. He found that a train having all the ca fitted with the vacuum brake, and running at 40 miles an could be stopped in less than the distance usually required for brakes, without ever using more than three inches of vacuu would be a great improvement in the everyday use of brakes, limit to the power to be used for ordinary stoppages, reservi full power for emergencies. He had not any practical experi the use of automatic brakes; but he thought the vacuum brak more easily be applied gently, by an ordinary driver, than any automatic brakes.

Mr. Joseph Tomlinson, Jun., said his opinion on this matt been so often stated that he had very little further to add. I been present at many brake trials, but had seen nothing yet t him to alter his original opinion, that a simple brake of a pc kind, in the hands of the driver, was the best at present obtained. He was not satisfied that any of the present aut brakes were to be trusted. What might be brought out in the he did not know. He was quite satisfied with the brake himself adopted, namely the Smith vacuum brake. Between and eight million stoppages had been made with it in five half years, and no accident had occurred by its failure. same time he should be happy to have a better, if he could get

Mr. D. M. Yeomans thought the time had come when o must give place to facts; and on that ground he thought Mr. had the best of it. With regard to the Smith vacuum br

would only say that, whether in the automatic or non-automatic form, he believed it was the most simple and reliable arrangement now extant. The Board of Trade, in asking for railway returns every six months, seemed to him to be doing a very wise act. Whatever stage of perfection had been reached at the present time in railway working, had been reached through experience; and he thought the same stage of perfection would be arrived at in continuous brakes, through the experience of the railway men to whom the question must be left.

Mr. GEORGE WESTINGHOUSE, JUN., referring to the Tables, said he was quite at a loss to understand why the totals added up in one way were so different from those added up in the other way. Thus in Table IV. the Sanders brake had a total given of 100 failures; but where the accidents were separated in various ways, the total came up to 154. With the Smith brake 264 failures was the total one way, and 307 the other way; while in the case of the Westinghouse brake 341 was the number given in one way, whereas the total the other way came to 549: showing there was some very singular way of arranging the various failures.

He would ask permission to give the opinion of Mr. Stroudley, of the London and Brighton Railway, who was not able to be present, but had written a letter on the subject. In this he remarked:—

"Previous to the introduction of the continuous brake on this line, we had very excellent arrangements of steam- and hand-brakes, which would pull up a train very quickly; but the want of automatic action in the case of a train getting off the line, or breaking loose, or from any other cause, had such weight with the company that it was unanimously agreed on the part of all the officers concerned in the working of the trains, as also the manager and directors, that the Westinghouse automatic air-brake was the most perfect brake that had yet been devised; and it was accordingly adopted, and will be applied to the whole of this company's stock. We have now about 100 locomotives and about 630 carriages fitted, and we are pushing this work as fast as possible.

"Our difficulties and so-called failures have really not b
failures, in the sense of the inefficiency of the brake to stop the tr
but have merely been slight hindrances to the traffic by reason
trifling defects, principally in the want of knowledge on the
of the staff as to the working; and, to a certain extent, in som
the details of the small pipes, which we have discovered
rectified. There has also been some considerable trouble with
original form of triple valve; this however has also been cured o
defects, and we have no trouble with the new kind, which have
advantage also of being simpler than the original ones. I h
only one instance on record, and that of a pin getting lost out of
brake gear, as a failure of the brake apparatus itself, during
whole of the time it has been at work; and this was discove
before the train had started, causing a delay of two minutes o
Every incident that occurs to the brake on this railway is d
reported, even when it arises only from the guard opening the ta
his van, out of curiosity or by carelessness."

Owing to the very great differences of opinion on the br
question, he thought that railway officials could hardly be expe
to come out very decidedly, on such an occasion as this, in favou
any particular brake. During his six months' absence from
country he had had a good deal to do with the brake in the Un
States; and there was hardly a company using a non-automatic br
that was not now negotiating with him to exchange it for
automatic brake, although the cost of the change was as grea
the original cost of applying either his old form or the Smith vac
brake. That would speak for the value of the principle more
anything else he could then say. The work of his firm on
side, in introducing automatic brakes, had been an up-hill fight:
their business on the Continent during the past year had increase
an enormous extent, and he believed the reason was that the br
were automatic. If he had to rely upon a non-automatic brake
should simply drop the undertaking; because, though non-autom
brakes might be adopted for a certain period, he was sure they w
all be changed eventually into automatic brakes. When he was
introducing his non-automatic brake in 1872, he had tried to argue

Sir Henry Tyler that if the couplings were made strong enough they would not break; but he found engineers would not adopt his brake, simply because of the liability to fail without warning, and because of the serious accidents that might then occur, when the driver was depending upon his brake. M. Banderali had suggested one point which he would give anything to accomplish: namely to make a brake which, when it got out of order, would make the fact known without putting itself on. If M. Banderali could succeed in that, he would confer on the railway world an altogether incalculable benefit.

Capt. Charles Fairholme asked leave to point out an error on the part of the Board of Trade, to which he had called their attention, namely that the Heberlein brake, which he represented, had not been classed in the First Division as fulfilling all requirements, and therefore not amongst those of which Mr. Riches had taken notice in his paper. It was put in as complying only in part with the Board of Trade requirements, because it was sectional; but he had pointed out that the sections were for convenience only, not of necessity, and that it complied in reality with every portion of the requirements; as was stated by the railway using it, the Maenclochog line in South Wales, where it had been working regularly for three years over gradients of 1 in 27. He might mention that the Heberlein brakes, as now being largely fitted in Germany, were exactly on the opposite principle to that of the English friction brakes. Instead of the driver pulling a rope to put the brakes on, he now took the brakes off by the rope, and applied them by slacking it. Consequently the brakes in their normal state were always on; and instead of telling the driver, when he was going forty miles an hour, that something was wrong, they would not let him get away from the platform unless everything was right. Thus the brake was in every way automatic, because it put itself on unless it was intentionally kept off, and because it applied itself the moment a coupling broke.

Mr. Riches in reply said it was a mistake to suppose that he objected altogether to automatic action. He did not object to automatic action when it could be obtained without what appeared

to him an excessive loss on the other side, through additio attachments and apparatus; and he thought the last paragra in the paper sufficiently showed that that was really his opinion.

He would first take the remarks of Mr. Sanders, who had object to the failures of the three descriptions of automatic brakes bei added up together for comparison; but in the Tables the failu and mileage run for each brake were given separately, which surely sufficient. The next point raised by Mr. Sanders was t the paper had omitted to show the cases in which the brakes fai to act when required. In the case of the non-automatic bra that was shown by the number of times the brake was rende useless; but with the automatic brakes it was not shown so fu For with the non-automatic brake, the period during which it rendered useless rarely exceeded the time it took to reach the n station, since a leaky joint could easily be made good against external pressure of the atmosphere, which was all that was need But when an automatic brake was rendered useless, especially working by pressure, it almost invariably remained so until the tr was taken to the repairing shed. Thus every stop the train had make, between the time when the brake was rendered inoperative the time of reaching the repairing shed, was in reality an occas on which the brake failed to work, though these were not given the Board of Trade returns, or in the paper.

He fully admitted the value of the "tell-tale" principle, contended for by Mr. Sanders; but the Board of Trade circular s the brake should be self-acting *in case of accident*, not merely in c of *accident to the brake itself;* and he maintained that, withou separation of the train, this automatic action could not come i force, except in cases when some part of the brake itself beca defective. He also held that the enormous number of cases in wh automatic brakes had become defective (of which some had, and sc had not, been indicated automatically) very forcibly pointed out t complicated automatic brakes were far more difficult to keep in rep and consequently far more likely to be out of order, than the simp non-automatic arrangements. Mr. Sanders had quoted the Ship and Wigan accidents as additional cases of trains parting; but h

those accidents were prior to the date from which he had started his enquiry; and his reason for starting in 1878 was because it was the first year that the Board of Trade returns gave this class of information, and hence, as it appeared to him, the year that would give the best results as to all the brakes.

Mr. Sanders had next pointed out that there were 107 instances of pipe-couplings being undone with the Smith brake; but such a defect affected the efficiency of that brake to a very small extent, so that the lack of intimation to the driver of such defects was not worth consideration. Mr. Sanders added that, "any of those separations of couplings might have led to very serious consequences." This was certainly taking a most extreme view of the case, as he himself had known the dividing of pipe-couplings to happen on trains working down an incline of 1 in 40, and the train to be pulled up with perfect ease at the platform at the immediate foot of the incline; showing, in his opinion, that such fears were entirely without foundation.

Mr. Sanders had next objected to his own brake being included with the other automatic brakes, because it was only rendered useless on one occasion; here again he might point out that each brake was shown separately in the Tables, so that there was no real cause of complaint. As to the case at Mill Hill, he agreed with Mr. McDonnell that the driver must have been to blame. The distant signals there were at a very considerable distance from the home, and if, on passing them at danger, the driver had applied his hand-brakes and whistled for the train-brakes, he should very nearly, if not quite, have stopped his train before reaching the home signals.

Next Mr. Sanders took exception to the statement that there were double the number of parts in automatic brakes that there were in the Smith brake; and went on to enumerate thirteen parts for the Smith brake, and seven only for his own. But he had omitted to count the fittings of his own brake in the same minute way as he treated the Smith brake. The following was the ordinary method of counting parts in these brakes:—for the Smith brake, one collapsing sack, two lines of iron pipes, and four hose with couplings, seven parts in all; for the Sanders brake, two cylinders, two pistons,

one line of iron pipe, two hose with couplings, and, in addition to ordinary brake gear used with the Smith brake, one rocking lever, additional connecting link, one balance weight, one connecting between the two cylinders, and one check-valve to prevent the re of air into the pull-on cylinder; or twelve parts in all. Added this there was upon each engine an air pump, with the neces valves, cocks, and attachments, in addition to the ejector, &c., wh last was common to the Sanders and the Smith brake.

With regard to the relative merit of the automatic and automatic brakes for working down inclines, he was convinced of accuracy of the remarks in the paper under this head, from his careful observations upon engines working trains down inclines, with the Smith brake and with two of the automatic brakes nan He had noticed that, when the latter were in perfect order, worked fairly well; but on trains which had been fitted with brakes for some considerable time, he had observed that the po which should be maintained to keep the brake on, decreased rapi through leakage during the operation. To recover this power, brake had temporarily to be released, which would be seen at to be a most objectionable feature; for of course, unless the ha brakes could be used, the train had to run without a brake du the time that this process of recovery was going on.

He would now turn to Mr. Gutch, who had appeared to de the Westinghouse brake. He admitted the apparent discrepa noticed by that gentleman between the title and the contents of paper. He had noticed it himself, and, but for unavoid circumstances, the title would have been altered as follows:—On practical value of Automatic Action, as at present applied continuous Railway Brakes: which would have removed objection. As he had throughout maintained, his objection was to automatic action, but to the complicated automatic brakes now use.

Mr. Gutch had next suggested that the comparison of failu drawn in the paper would cut both ways, as the brakes of Mes Fay and Newall had no failures recorded against them in the Boar Trade returns; but his reply was that those brakes were

really continuous, but merely sectional, and that they did not fulfil the Board of Trade requirements at all. In addition, as stated in the early part of the paper, he had only taken the Smith brake as a representative of the non-automatic side of the question.

Next Mr. Gutch had objected to the suggestion No. I., on page 101 of the paper, as to comparing the number of accidents in which automatic action had either prevented or mitigated disaster, and the number of accidents caused by defects in automatic attachments; and said that if an accident had been prevented it was not recorded at all. But if Mr. Gutch had carefully read the paper, it would have shown him that the instances where automatic action had had an opportunity of showing its merits were enumerated, and also those where it was possible for benefit to have arisen from its presence; and as to there being no report of instances where automatic action had prevented accident, he would ask in what instances an automatic brake *could* prevent a collision, while a non-automatic brake could not, excepting of course when a train became separated; and under what circumstances such an accident as a train becoming separated was not reported to the Board of Trade. This point should be clearly understood, for Mr. Gutch seemed to imply that an automatic brake could do more than a non-automatic brake. This was not so, with the one exception of the separation of trains; and all such separations should be reported to the Board of Trade. Of course the non-report of instances where collisions had been avoided affected all brakes without distinction.

Next Mr. Gutch had argued that the better a brake had fulfilled its duty, and prevented accidents, the worse the comparison that could be made about it. That was an extraordinary view of the question, for it would be seen that the number of failures formed the whole basis of the comparisons in the paper; hence, when a brake ran without failure, it must show to advantage as compared with others, and not the reverse. Mr. Gutch proceeded to say that, by aid of an automatic brake, a railway might be kept clear of accident for a whole year, and yet if there were fifty failures of brake material the paper would argue that the brake had not succeeded. But the paper did not pretend to set up a standard

of excellence, but only to compare impartially the working of different brakes. For instance, if two railways were taken, each using a different kind of continuous brake, and if each brake had run an equal number of miles without collision, but in doing so one had a greater number of failures in material than the other, then he should certainly argue that the brake which had the excess of failures was the less reliable and the worse of the two.

In reference to Mr. Gutch's remarks on the Board of Trade requirements as to automatic action, he would ask whether Mr. Gutch believed that the Board of Trade, in making those requirements, contemplated that a passenger train should be peremptorily "pulled up" directly the most minute defect showed itself in any of the details of a brake; and should thus cause detention in tunnels or other objectionable places. Did it not rather appear that the intention of the Board of Trade was that the brake should hold both parts of a separated train, and, at most should indicate when any serious defect occurred in the fittings? Mr. Gutch pointed out that many accidents happened through fractured tyres &c., and expressed his belief that the only safeguard must necessarily be an automatic brake. But would he attempt to say that no non-automatic brake could be of equal service in such instances, in which it very frequently happened that severance of the train did not occur, or, if it did, almost invariably not until the main damage was done? And the accidents quoted in the paper showed that under certain circumstances, even where the train did separate, automatic action was practically of no use.

With regard to cases of broken couplings not mentioned in the paper, he had omitted that at Methley Junction, because the express was not properly a passenger train at all, being chiefly composed of mixed trucks. As to the accident on the Great Northern Railway of Ireland, he had not been able to obtain sufficient information to deal with it; and the Kirkgate accident was stated to be due to the driver running at an excessive speed. With regard to the Bickley accident, the experiments with the Westinghouse brake on the North Eastern Railway, in July 1879, showed that a train could be stopped from a speed of 51 miles an hour in 207 yards, and from 27 miles an

hour in 68 yards. On those data the train at Bickley should have been reduced from 45 to 25 miles an hour in about 140 yards, and should have stopped altogether in about 200 yards, instead of having a speed of 25 miles an hour after running 215 yards. Hence he could not accept the performance of the brake on that occasion as satisfactory.

Mr. Gutch next endeavoured to show that, as couplings did break, the suggestions in the paper as to stronger couplings were fallacious. Now the list of defective couplings returned by the Board of Trade gave only the number quoted in the paper, and referring to "couplings of passenger trains"; but there were many other failures of couplings with goods and mineral trains, and some of these were the primary cause of accidents to passenger trains; as for instance, when, on an incline, a portion of the goods train ran back on a passenger train which was following. There it would be seen that no brake, continuous or otherwise, upon the passenger train, could have controlled the goods train; therefore all those cases could only be obviated by increased strength of couplings. And as to Mr. Gutch's remark that in an accident a power could be brought to bear sufficient to break any coupling, he would ask for a definition of this power. If it was meant that when carriages fell over embankments couplings would be broken, he would admit the fact; but would automatic brakes be of any use, if severance occurred only in such cases? If it was meant that the brakes would themselves cause breakage of couplings, he should reply that any brake capable of parting a train was an inefficient brake. With regard to couplings becoming unhooked in passenger trains, that defect was rapidly disappearing upon all lines, by the increased use of the lipped coupling hook.

Mr. Gutch had next called attention to the differences existing in the returns made by the various railway companies to the Board of Trade, and the seemingly different interpretations given by these several lines to the instructions. But, whilst admitting the fact, he must at the same time observe that it cut both ways. Different railways gave special attention to different brakes, so that what was omitted on one line was made up for on another; and finally the comparisons were brought out pretty accurately. Mr. Gutch

considered it unfair to compare an automatic brake which recorded its own failures with a non-automatic brake which did not. But the Tables distinctly enumerated the number of cases in which each several brake was found defective, whether it indicated the fact itself or not; if there were cases in which a brake was out of order without its being found out at all, he did not see how those were to be treated. Mr. Gutch did not consider however that the word "failure" should be applied to automatic brakes, in cases where they showed themselves to be out of repair, because these instances were really successes. He must emphatically contradict tha statement, for, whenever those indications of defect occurred, a failur of some part of the brake apparatus must have taken place. Fo instance, it was clearly a failure when a train was delayed twenty five minutes on the North Eastern Railway, by the Westinghous brake persistently going on three times when not required. The fa of such cases being indicated was of course an advantage, particularl with brakes whose failures were frequent. But a failure must b admitted when any brake did that which it was not then required t do; and the fact of the failure being indicated was not a success fo the brake, but only for automatic indication, which every one mu desire to see carried out in the most complete but simple way possibl

Mr. Gutch had asserted that the paper was wrong in stating th automatic brakes had frequently been rendered useless, until th train had been taken to shed; but he would most emphatically repe the statement in the paper, as he had been informed on undeniab authority that it was the case upon more than one railway. H information had been obtained, not only from the Board of Tra returns, but also from railways where the failures had occurred. Wi regard to his own acquaintance with other than the Smith brake, n doubt that was the brake used on the Taff Vale Railway; but he ha closely watched the workings of all the brakes named in his pape excepting only the Steel brake.

As to Mr. Gutch's remarks upon the different tone about th failures with the automatic and the non-automatic brakes, it w true that with the former class there were failures recorded, in number of instances, from petty defects of the brake apparatu

but those small matters did occur, and did produce failure, which in his opinion should not be the case with a thoroughly good brake; for very frequently those small defects would entirely disable the apparatus. As to the case of a guard misusing, with intent or otherwise, any of the brake attachments, if these were fewer, and also less complicated, there would certainly be less risk of such mistakes occurring.

His opinion of the results of the Tables was completely opposed to Mr. Gutch's; for whereas that gentleman considered that they told against the vacuum brake, he held that they were strongly in favour of it. And as to the relative importance of the failures, he could say, from his own knowledge of the influence of such failures on the Smith brake, that the percentage of failures which would constitute danger on inclines was certainly not more than from 10 to 12 per cent. at the outside, instead of the proportion given by Mr. Gutch. Then as to the percentage of cases in which the Westinghouse and Smith brakes were rendered useless, he would point out that the comparison of efficiency should not be based upon such a percentage; for the larger the number of other failures recorded against a brake, the smaller this percentage of dangerous failures would become. Therefore he maintained that the best method of comparing the merits of brakes was to estimate them upon a basis of mileage run, as was done in the paper. Nor could he accept Mr. Gutch's suggestion to take the North Eastern alone, for obtaining information upon the working of both brakes; because more than one pamphlet advocating the Westinghouse brake had appeared from that quarter.

Mr. Gutch had next objected to the term "creeping on," as applied to the Westinghouse brake. He could only refer to the Board of Trade returns, which distinctly named that defect; but, as the triple-valve had been since improved again, he hoped it had now become less complicated, and more reliable in that particular. As to the idea that when the brakes applied themselves it was caused by the breaking of pipes, that was frequently the case, and then the brake suddenly went on and pulled up the train; but the "creeping on" was not caused in this way, but by minute leakage, which, as the reports said, "gradually puts the brakes on, and finally stops the train."

As to the Wemyss Bay accident, no doubt the signalman's
was the primary cause; but if the brake had not refused to re
upon the leading train, that train would have been out of the
before the following train could have reached it. If, as Mr. G
said, the cause of brake-blocks being found tight upon wheels
their not having been properly taken off at the previous stop, c
it be held that a brake worked satisfactorily, which was capab
taking off the blocks from part of the train and not from the wh
It could not be that many blocks remained on, otherwise the en
could not, without extreme effort, start the train. The remark,
when the Westinghouse brake was applied, it went on everyw
at once, sounded strangely in the face of the recorded insta
where trains had been broken into sections by the action of
brake. True, Mr. Gutch sheltered himself by saying that wa
care in the handling or supervision of the brake might caus
to work irregularly throughout the train; but did not this admis
support his own view that these automatic brakes were
complicated to work, and hence more liable to mismanagement?

Mr. Gutch had spoken of his experience in working
Westinghouse brake upon long inclines; but he then went o
mention "experiments," and he himself had strong doubts whe
the ordinary working of regular trains would show by any means
desirable results as experiments specially arranged. As to
unsuitableness of the Smith brake on inclines, he could only say
with this brake a regular service of trains had been working up
down three inclines of 1 in 40, and one whose average gradien
nearly six miles was 1 in 55: and that these trains had
running, in some instances, twelve or fourteen trips per day
between two and three years, without the least difficulty or mis
using the brake as required, both on the up and down jou
This, he thought, must be received as a practical reply.

He would now turn his attention to Sir Henry Tyler's rema
the first of which was that, when continuous brakes were
generally used, trains would be run at a greater speed up to stop
places &c., and then any accident which happened would be
serious than before: but surely such a practice would neve

adopted upon any well-managed line. His own idea had always been that these brakes were to be additional safeguards, and not treacherous appliances to tempt people to carelessness. The suggestion that he condemned automatic action was quite undeserved, as already shown. With regard to his having confined his statistics to the eighteen months commencing January 1878, he would point out that all the brakes enumerated had undergone gradual improvement ever since their introduction upon English railways; and therefore this limited and recent period (long enough to give a fair idea of their working) should properly be taken to obtain the information sought, because it would give the best results in each case. Looking at the fact that continuous brakes had so largely reduced the number of accidents to passenger trains, it seemed of little use to go back to the days when we were without such brakes; especially as under Sir Henry Tyler's heading of "Instances where automatic action was needed," would be found many cases where the accident would have been altogether avoided, had the train been fitted with any of the now known continuous brakes. But even Sir Henry Tyler himself could only show (with all those favourable circumstances) a total of 8 per cent. of cases requiring automatic action: and this must be admitted, when all things were considered, to be a very small proportion. The other objections made by Sir Henry Tyler were, more or less, repetitions of those made by previous speakers.

Mr. Price Williams and Mr. Westinghouse had found great difficulty in understanding the totalling up of the failures in the Tables. He might explain that the figures given in column (11)—"Total recorded failures,"—represented the number of individual instances where the brake in question became defective from any cause; and the figures given in columns (3) to (10) analysed those failures according to their individual headings. This produced a little complication; for instance, if a porter, by mistake, had turned one of the stop-cocks the wrong way upon a carriage fitted with a Westinghouse brake, that fault of the *man* would be entered in column (3); and it would be shown also in column (4), because that cock was an additional attachment necessary to make the brake automatic; and, if this additional fitting *had* not been there, the

mistake could not have been made. But although these two e
were made in columns (3) and (4), yet the case would only be co
as one failure in the "Total failure" column. As to Mr.
Williams's remarks on percentage of failures, he had dealt wit
in replying to Mr. Gutch's question on the same subject.

In conclusion he had only to express his satisfaction
discussion which his paper had elicited, and also to than
President, Council, and Members of the Institution for the kin
in which they had welcomed his efforts.

Mr. Robinson said that, before the President put the v
thanks to the meeting, he felt it was only due to Mr. Riches to
out that the welcome which the Council had given to the pap
Mr. Westinghouse on the one hand and of Mr. Sanders on the
without any paper having been read about the Smith va
brake, had apparently led some persons rather to imagine that
the tendency of the Institution to be partisans of automatic a
as represented by the Westinghouse and Sanders brakes. The C
had therefore tried to get some one to read a paper on the
vacuum brake, but in that they had failed; and it was only
say that some pressure had then been put upon Mr. Riches to
before them the paper, which he had just read, not as a parti
any particular brake, but as a disbeliever in automatic action
present applied.

The President proposed a vote of thanks to Mr. Riches f
paper. He thought they were all very much indebted to hi
the trouble he had taken and the care with which he had an
the returns. It could very easily be understood why rival inv
had not agreed to analyse returns exactly in the same ma
but he believed that Mr. Riches had done it perfectly ho
and solely with a view to promote discussion.

He thought he was only expressing the feeling of the meet
saying that they hoped the Board of Trade would analys
so-called failures more thoroughly as to their *character*; n
whether in fact the circumstances that occurred were in fav

the brakes or against them. He had himself hoped to hear more in reference to the life of india-rubber, exposed so much to the air as it was in some of the forms of brakes; and, as to whether it was not advisable to renew it from time to time. He much regretted to hear that the adoption of the real block-system did not make more rapid progress on the Continent; for in his opinion it was undoubtedly the right system for preventing accidents, and the cost of a few extra signal boxes and men ought not to prevent its adoption.

The vote of thanks was passed.

The PRESIDENT proposed a vote of thanks to the Institution of Civil Engineers for their kindness in granting their rooms for the meeting, which was carried unanimously.

The Meeting then terminated.

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permeated by small cavities or bubbles. It descends along axis of the ingot far below the apex of the cone, and forms places, hollows of considerable size. Following a direction rece radially from the central axis of the casting, the porosity dimini and becomes, at last, imperceptible to the eye; so that a ce thickness of metal, included between the spongy crust and the po heart, appears to be sound and compact.

Under certain circumstances, to which further allusion wil made, bubbles are not formed, or at any rate in a very slight de only, at the outer surfaces of ingots cast in metallic moulds; instead a strongly-marked acicular, or needle-like, structure beco apparent, as illustrated on the lower side of Fig. 1.

An examination of the fractured surface shows that the acic layer consists of a conglomeration of irregular prismoidal bo arranged at right angles to the sides of the ingot, as shown size in Fig. 2. The cohesion between the prismoids is great, so that ingots having this structure break up with compar ease, fracture taking place along the facets of the prisms presenting a dead silvery hue.

Within the acicular layer comes a more or less pronou granular structure, composed of irregular many-sided grains shown two-thirds full size in Fig. 3, having a dead silvery co very similar to that characterising the surfaces of the prism Within this layer comes the compact metal, having a brilliant fracture; and then follows the porous portion, which becomes open as the core of the casting is approached.

Each of the above-named defects requires to be examined in t

The imperfection, the origin of which is most easily explai is the funnel-shaped cavity in the upper end of the ingot, cause the setting of the metal. The solidification, hastened by the co influence of the sides of the mould, necessarily takes place in la following its inner surface. According as the layers grow thi the level of the liquid sinks, because the volume of the n decreases and gives room to the still fluid central column, w as it falls, also constantly diminishes in diameter at its upper sur

The phenomenon described is so well known and understood by founders that it is unnecessary to dwell further upon it.

The bubbles permeating the outer surface of an ingot present one of the most important defects met with in steel castings, and have long been the subject of enquiry by many metallurgists. With respect to the origin of the gases occluded in fluid steel, it cannot be said that any unanimity of opinion exists among those who have investigated the matter. Some, for example, are inclined to attribute the presence of gases simply to the solution of the products of combustion of the furnace in the fluid steel, during the time it is melting; others hold the opinion that they are merely the products of chemical reaction, taking place between the elements constituting the fluid steel, and the substances forming the linings of the furnaces and of the ladles used; others again ascribe the formation of the gases to the reactions which take place between the elements composing the fluid steel, under the influence of oxygen derived from the products of combustion or from the atmosphere.

It is unnecessary to examine critically these conflicting opinions: each of them is based on factitious data, and cannot be authoritatively proved erroneous. It should however be added that each of the above-mentioned causes contributes, together with the rest, in generating gases; which thus appear to be the result of their combined and simultaneous operation.

The ordinary view, which has not been controverted, is that the great bulk of the gases produced is composed of carbonic oxide;* and it is very generally allowed that the period at which the largest quantity of gas is formed is at the point of transition from the fluid

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* Within the last year Müller has stated (Berichte der deutschen chemischen Gesellschaft, 1879, No. 1) that analyses of the gases from the pores in steel castings have yielded from 60 to 90 per cent. of hydrogen, the remainder of the gas being nitrogen, with only a small quantity of carbonic oxide. If these results are confirmed by more extended observation, they will open an entirely new field of speculation in the metallurgy of steel.

to the solid state. On considering this phenomenon more closely, it easy to see that it is subject to the laws which govern the soluti of gases in other liquids. In fluid steel, as well as in other liqui saturated with gas, the greatest evolution takes place when t mass is agitated, or especially when the liquid is poured fro one vessel into another. Accordingly, in pouring steel from t Bessemer converter into a ladle, or from the ladle into t mould, violent ebullition, with a copious evolution of gases, tak place. If there were no risk in cooling the steel, and if it could protected from the action of the oxygen in the air, a successi of pourings would be sufficient to remove the whole of the imprison gases.

Steel cast into a mould, and allowed to cool, immediate commences to evolve gas in the form of very minute bubbles, whi adhere to the first particles of steel solidified against the sid of the mould. In consequence of the property possessed dissolved gases, of escaping into space or into bands of alrea existing bubbles, the bubbles which have fixed themselves to the fi portions of solidified steel grow rapidly by the influx of gases fr the metal surrounding them. Inasmuch as the thickness of solidified layer is always increasing, in consequence of the cooli influence of the sides of the mould, the augmentation in volume the bubbles must occur exclusively, or nearly so, in a directi perpendicular to the sides. In this way the form of a bubble m vary in accordance with the varying rate at which the bubble gro in volume, compared with that at which the thickness of the solid la increases. If the bulk of the bubble increases more rapidly than thickness of the solid layer increases, then the diameter of bubble becomes greater as it recedes from the sides; and it assum the shape of a cone with a spherical end, the larger diameter be turned towards the centre of the ingot (Fig. 4, Plate 8). When the ga under these circumstances, collect too rapidly, the enlarged portion the bubbles grow very quickly, and are from time to time torn off float to the surface. If the growth of the bubbles coincides with rate of thickening of the solidified metal, then the bubbles beco of a cylindrical form with a hemispherical termination (Fig.

Finally, if the setting of the steel goes on more quickly than the accumulation of gas, then the bubbles gradually taper away inwards to a point (Fig. 6); bubbles of this last character however are extremely rare.

As the mould fills, the pressure of the fluid column on the lower layers of steel continually increases, and, at the same time, the facility with which the gases separate from the metal decreases; consequently the further development of the bubbles in the lower layers is arrested. The bubbles become sealed in, and the subsequently formed layers solidify free from bubbles, unless a fresh evolution takes place from an accidental reduction of pressure. When a bubble becomes thus sealed up, a contraction-cavity is formed at its apex; the interior of this cavity is lined with crystals, to which particular attention will be directed later on.

From the foregoing it is evident that, if it were possible to arrest the formation of the original minute bubbles, which affix themselves to those particles of steel which first set on the sides of the mould, the solidifying surface of the ingot would not then be permeated by the ever-growing bubble cavities. The bubbles that would form, having no attachment to the sides, would float up readily to the top, and leave the surface of the casting perfectly solid.

The phenomenon of the adhesion of particles of steel to the walls of the mould is analogous to the wetting, by water, of the sides of a vessel. The hotter the steel, the less the sides of the mould are wetted as the metal is poured in; and on the other hand the more refractory and impermeable to heat are the materials forming the mould, the less are the chances of their sides being wetted, and of particles of solidified steel sticking to them. From these considerations it may be concluded, (1) that hot steel, which will not wet the sides of a metallic mould, will yield castings free from bubbles in their outer surfaces; and (2) that steel hot enough not to wet the sides of a sand mould, while cool enough to wet those of a metallic mould, will give sound castings in the former case and porous castings in the latter.

Experience quite justifies these conclusions: very hot steel does give a sound casting, even in a metallic mould; and does so, as a

matter of course, in a well dried and warmed sand m
exception being only those places which have been splash
metal in pouring; to these the steel has in fact adhered,
are therefore easily wetted. An extremely interesting ex
which has been frequently repeated, namely that of
moderately hot steel into a mould half metallic and h
with sand, always gave ingots porous on the side in contact
metallic mould, and perfectly sound on the side next to the
lining. Fig. 7, Plate 8, represents an actual section of such
reduced to one-eighth its natural size.

What has hitherto been said as to bubbles has refere
period of filling the mould with steel, and to the first mom
casting; during which time the gases can easily escape
atmosphere, partly through the free uncovered upper surfa
metal, and partly by means of the bubbles which float
burst there. As soon as the upper surface begins to b
by a solidified layer, the free escape of gases becomes more
while their solubility decreases* in consequence of the lower
temperature to the congealing point; the gases then coll
the top crust, acquire considerable tension, and by that me
the further formation of bubbles even in the highest laye
ingot; while those previously formed become locked u
solidified outer layers, and thus further evolution of gas
completely checked. If however the top crust happens to
then the collected gases burst through it, and the partially
in the form of a foamy mass, breaks through with them; the
is thus suddenly relieved, and a fresh evolution of gas tak
accompanied by the formation of a second row of bubbles,
the upper portions of the casting.

The points to which this second row of bubbles becomes
are the imperfectly closed contraction-cavities of the first r

* Although, according to the law of the dissolution of permanen
liquids, their solubility increases with the fall of temperature of t
yet this law only holds down to temperatures more or less
temperature of congelation, and does not therefore apply to the case in

explains the existence of a sharp line of demarcation between the bands containing the first and the second line of bubbles, as may be seen in Fig. 8, Plate 8, where the right-hand boundary of the shaded portion is that between the liquid and the solid metal, at the moment of the reduction of pressure caused by the rupture of the upper crust of the ingot.* For greater distinctness this is drawn on an enlarged scale.

But notwithstanding the circumstances which have just been described, the evolution of gases, even beneath an unbroken crust, does not altogether cease until the solidification of the very last particles of steel in the centre of the ingot has taken place. The cause of this persistent evolution is the reduction of the pressure in the gases collected under the upper crust, partly from the gradual cooling of the mass, and partly from the increased space afforded by the growth in volume of the contraction-cavities. These circumstances explain the reason why the upper portions of steel castings are permeated by so many bubble-shaped cavities.

These defects occur even in compressed steel. Figs. 9, 10, and 11, Plate 9, which represent a compressed steel ingot 21½ in. diameter, 5 ft. 7 in. long, and weighing 3 tons, illustrate clearly that if the pressure ceases before the central portions of the castings have set, the evolution of gases commences in the still fluid portions: the reason being that the reduction of bulk in the metal causes a partial vacuum, and so draws out the gases. The same thing occurs, even under prolonged pressure, if this is not sufficiently intense, in which case the plunger cannot follow the shrinkage of the steel, but is arrested in its motion by the solidification of the outer portions of the casting. The ingot represented in Plate 9 was pressed for three quarters of an hour; while it has since been ascertained that one hour and a quarter is necessary to produce sound work.

The internal surfaces of the bubble-shaped cavities generally present a clean silvery appearance. But as the side bubbles have

* In order to hasten the formation of an upper crust on the ingots, they are either covered, immediately after pouring, by a cold iron plate, or have water poured on them.

their origin very close to the outside surface of the ingot, and are only divided from the atmosphere by thin diaphragms, it often happens that these are either broken or rusted through during the cooling of the ingot; and, communication being thus made between the cavities and the air, the sides of the cavities become covered with scale, or assume iridescent colours, according as the air has more or less freedom of access. The upper funnel-shaped contraction-cavity has also an oxidised surface, because the rupture of the crust covering it, before it finally sets, allows the access of air to its interior.

The next point for consideration is the setting of the interior liquid steel, and the growth of the solid layers from the external surface to the centre of the ingot.

On examining the sides of the contraction-cavities, it will be noticed that they are covered by minute crystalline growths, formed by the piling up on one another of steel crystals. The accumulation of such growths in the funnel-shaped contraction-cavity, and especially at its lower end, forms a porous mass in which considerable cavities frequently occur. The general appearance of the lower part of the funnel is illustrated full size in Fig. 12, Plate 8; and Fig. 13, Plate 10, represents a group of crystals taken from the central contraction-cavity of a steel ingot, 47 in. diameter, and weighing 27 tons, at a point about one-fourth of its length below the upper end. This is drawn four times the natural size.

On examining the separate crystals under a microscope, it becomes apparent that they are of the skeleton or discontinuous type, with the larger development of branches in the direction of the octahedral axes. The growth takes place in such a manner that the increase in the direction of one of the principal axes of the crystal is always more rapid than in those of the other two axes, so that each discontinuous crystal presents the appearance of the skeleton of an elongated rectangular octahedron. Besides the growths in the direction of the octahedral axes, which may be called growths of the first order, branches of the second, third, and other orders appear, as the distance from the summit of the group increases; these growths being at first rudimentary, but becoming more and more developed

as they approach the base of the crystal, until they sometimes literally form the skeleton outline of a complete octahedral crystal. An illustrative diagram of such a structure is given in Fig. 14, Plate 10. The largest isolated steel crystals which have been observed, though only rarely, have a length of 5 mm. (0·20 in.); in most cases the length reaches only 3 mm. (0·12 in.) with a diameter of 1 to 1½ mm. (0·04 to 0·06 in.) It is difficult to assign a minimum limit of size, because well-developed crystals have been found, with very accurate contours, so small that they could be clearly seen only when magnified from 100 to 150 times.

The various discontinuous crystals are not usually arranged parallel to each other. Their principal axes intersect at every imaginable angle, as may be seen in Fig. 13. Sometimes however they assume a twin arrangement like that represented in Fig. 15, which is taken from the contraction-cavity of a 5-cwt. steel ingot, and is enlarged 70 times. Fig. 16 represents the outline, enlarged 25 times, of one of the crystals of the group represented in Fig. 13.

Inasmuch as the sides of the contraction-cavities, and of the porous portions surrounding the central contraction-space, are invariably built up of more or less developed discontinuous crystals, it is perfectly justifiable to conclude that the setting of steel does not take place by the uninterrupted addition of smooth layers, but by a continued growth of discontinuous crystals in a radial direction from the cooling surfaces of the mould towards the centre of the ingot; and further that the principal axes of the growths are disposed at right angles to the cooling surfaces, in the manner illustrated in Fig. 17, Plate 11. This is demonstrated in the clearest manner by the radiated structure of the fractures of ingots cast in metal moulds, when the fluid steel has been so hot that no gas bubbles or very few, are found in the outer layers. If the diameter of a cylindrical ingot is small, say from two to three inches, then the rays penetrate to the very centre, as illustrated by Fig. 18; but if the cross section of the ingot is rectangular, Fig. 19, then the fracture shows a rectangle with clearly defined diagonals, formed by the final meeting of the crystals in their growth normally to the surfaces of

the mould. Along these diagonals lie the planes of weakness so well known in ordinary iron castings. It should be noted also that in the contraction-cavities of ordinary iron castings are found discontinuous crystals very similar to those that have just been described; it may consequently be inferred that the setting of cast iron takes place in the same manner as that of steel. Fig. 20 represents a crystal from a contraction-cavity in grey cast iron, enlarged 140 times.

From numerous observations on the structure of the sides of contraction-cavities, it appears that the harder the steel, that is to say the more carbon it contains, the clearer is the development of the discontinuous crystals. In very mild varieties, containing less than 0·2 per cent. of carbon, it is difficult to find well-developed crystals; and when discovered they are of insignificant size. It is highly probable that an intimate relation exists between the faculty for the regular development of discontinuous crystals, and the power of the metal to change rapidly from the perfectly fluid into the solid state, without a more or less protracted passage through the soft dough-like condition, which latter would naturally interfere with the rapid and regular development of the branches of the crystals. This may be seen even in cast iron. The white varieties, or those qualities which are susceptible of being made white by chilling, assume a ray-like structure, indicating a rapid formation of crystals. Grey irons, on the other hand, in which the segregation of graphite hinders the regular process of crystallisation, and which tend to assume the dough-like condition before solidification, take a granular structure; the metal, which at this time tends to form into discontinuous crystals, and to reject the graphite in the neighbourhood of the growths thus being formed, contains very little carbon, although it probably retains all the other substances associated with cast iron. With respect to the confused manner in which the axes of the groups of crystals, in the contraction-cavities and in the central porous column, are disposed, it should be remembered that the cooling in these parts takes place very slowly, through the heated and recently solidified sides of the ingot; and that this state of things is favourable to the formation of a great number of centres of crystallisation, with perfect freedom of direction to the main axes. *Besides this,* the central portion of the cooling ingot is always in a

state of motion from the shrinking and setting of the metal; and this motion, although very small, is quite competent to turn and disarrange the axes of the crystals.

The chemical composition of the discontinuous crystals, according to the analyses made at the Abouchoff Works, is by no means constant; and is always the same as that of the general mass of the ingot, be it hard or mild steel. Consequently there are no grounds for supposing that a crystallisation is taking place of some definite chemical compound of iron and carbon, although the phenomenon of *liquation*, first noticed and proved by Messrs. Lavroff and Kalakutzkin,* may have given grounds for such a supposition. The discontinuous crystals found in the spots produced by liquation have the same composition as the metal of the spots; but as this metal is always harder than the rest of the ingot, so the crystals are distinguished by more delicate outlines than are characteristic of those which are found outside the spots, and of which the composition is identical with that of the bulk of the ingot.

Turning again to the form of the crystals, it is noticeable that there is no strict regularity in their growth. Sometimes the growth of one side exceeds that of the other; sometimes the branches of the second order grow more rapidly than those of the first, depriving the latter of the material from which they were formed, and then in their turn throw-out branches of the third order, and so forth; sometimes the branches meet, unite, and enclose between themselves spaces filled with fluid steel. Fig. 15, Plate 10, represents such spaces, *a*, *a*, locked in between the growths of the first and second orders. And all this is seen in the examination of one crystal formed by itself. How many of these locked-in spaces must be formed when neighbouring crystals grow side by side and throw out branches in all directions! What takes place in these spaces during the further setting of the steel? The fluid metal continues to act as the source of supply to the growing crystals; but as this involves a shrinkage of the volume of the metal, it follows that each space becomes a contraction-cavity, which may be named, for distinction's sake, a partial or local cavity.

* *Journal of the Imperial Artillery*, 1866, 1867.

It is evident that the supply of material for the re development of the crystals cannot go on, if the metal bec viscid and loses its fluidity; but in the centre of the ingot thi of fluidity does take place, and is the reason why the structu the steel becomes more and more porous as the centre of the ca is approached. Near the centre the mass becomes, in fact, more than a collection of local contraction-cavities. One of cavities is exhibited in Fig. 21, Plate 12, enlarged 80 times.

On the other hand, the more closely the crystals are p together, and the quicker their branches grow, the more diffic becomes for the metal to flow to the crystals in course of form notwithstanding that the steel remains very fluid. This sta things exists during the formation of the external layers of an cast in a metallic mould, which rapidly cools the surfaces in co with it. This is the cause of the formation of the acicular layers, and of the comparatively weak lateral adhesion of component prisms or needles. The local cavities under circumstances arrange themselves, for the most part, along the p of contact of the crystals which are forming in directions at angles to the surface of the ingot. The cross sections of prisms are generally irregular. This irregularity is caused, in first place, by the direction of the lateral axes of the neighbou crystals having no relation whatever to each other; in the se place, by the distance between their principal axes not being e so that those very near to each other tend to form twin, triple, other branches, while the more distant ones develop themselves independently; and in the third place, as has been already poi out in describing isolated crystals, by the rapidity of the growt branches being rarely symmetrical in reference to the principal From these considerations we may imagine the cross sectio growing crystals to be similar to that illustrated on an enlarged in Fig. 22, Plate 12. At the termination of the growth, the prob appearance of the contiguous crystals is represented in Fig. 23; indeed this appearance may be actually observed in the fractur steel ingots of acicular structure. The growth of crystals norm to the sides of the ingot is represented in Fig. 17, Plate 11.

The weakness of cohesion between the prismatic crystals is the chief cause of the formation of external cracks during the cooling of the ingots. The slightest inequality or roughness in the sides of the mould, hindering the free contraction of the cooling external layers, is sufficient to destroy the connection between the prisms, and to cause minute cracks, which are the more numerous the hotter the metal has been, and the greater the consequent contraction. The surfaces of the cracks have a prismatic structure, and the imprints of the discontinuous crystals may be distinctly seen. Fig. 24, Plate 12, represents, full size, the surfaces of a crack which took place, at a bright red heat, during the setting of the external layers of a steel ingot, while the central portion was still fluid. In castings of large diameter, say from 30 in. to 50 in., and of considerable height, say from 7 ft. to 10 ft., and when the steel is very hot and is poured quickly into a metal mould, the rapid expansion of the sides of the mould, acting in a contrary direction to the contracting layers of the steel, has an especially marked influence on the formation of cracks in the skin of the ingots. This inconvenience may in a great measure be obviated by pouring very slowly.

Besides the formation of cracks, the rayed structure of the external layers produces another effect; namely that during the cooling, which takes place more rapidly in the outer than in the inner layers, the former are necessarily thrown into a state of tension, and stretch in consequence; not so much however by the extension of the metal itself as by the destruction of cohesion, and by the separation between the contiguous crystals forming the outer layers, as shown in Fig. 2, Plate 7.

With respect to the granulation which takes place in cooling, inside the outer prismatic surfaces, it can be explained by the fact that this portion of the casting must be in a state of tension while the metal is setting. It has already been explained, in the author's paper on the Manufacture and mode of working of Steel, that, when raised to a high temperature and cooled slowly, steel sets in the form of irregular many-sided grains. If, during the building up of these grains, and while the mass is still red hot, the cohesion of the

metal is enfeebled or destroyed by the action of external forces tensile or bending stresses, then the chief destruction of coh will take place between the surfaces of contact of the grains, consequently, in the fractured surfaces, detached grains will app

This effect may be produced artificially. A piece of steel o form *a*, Fig. 25, Plate 12, is heated for five or six hours to a b red or yellow heat: it is then removed from the furnace, placed between lugs *bb*, projecting from a massive cast-iron pla arranged that the steel is securely held from contracting. piece of steel will be stretched slowly as cooling proceeds; and cohesion among the grains, which have been formed during the exposure to a high temperature in the furnace and the subseq slow and quiet cooling, will be loosened. If the granulation has very strongly developed, the bar will either tear asunder of itse will be very easily broken after it is cold; the fracture exhib clearly the granular formation. The same effect may be produce dropping a steel ring, heated as above described, on to a cast-iron Hard steel is found to granulate more quickly than the milder vari

Inasmuch as during the passage of steel through all the ra of temperature, from its setting point to that of the ordi temperature of the atmosphere, the strains in the various parts o ingot are constantly changing from tensile to compressive or *versâ*, we may expect to meet with such granulations in all por of a casting; generally however they appear in the outermost the innermost layers, and especially, in ingots of large diamete the places where there is a great difference of temperature bet the outer and inner layers. At the commencement of cooling outer layers of an ingot are stretched, and the inner ones compre at the conclusion of the cooling the reverse action takes place outer layers being compressed and the inner ones strongly exte The tension of the inner layers in ingots of large diameter, su 40 in., is at times so great that, if left to cool in the open ai ingots often exhibit internal cracks, especially in their upper weaker ends.

With respect to the details relating to the granulation of the remarks made in the paper of 1868 are still applicable. Fi

and 26, Plates 7 and 13, represent, at two-thirds the natural size, fractures of a highly granulated ingot. One half of the piece, from which Fig. 26 was taken, is in the museum of the Imperial Russian Technical Society, and one of the grains is illustrated in Fig. 27, magnified seven times. Fig. 28, Plate 12, represents a grain out of another piece, also magnified seven times. It is evident that these grains have only a slight likeness to regular crystals; there is no regularity of form or angle, and the edges are more or less curved and crooked.

We must next consider the methods adopted for overcoming the defects which have been discussed above.

A roundabout way of attaining the object sought is the use of so-called "malleable cast iron." The articles to be produced are cast in white refined iron, and are then exposed for a long time to a high temperature, in some slowly oxidising medium, the effect of which is to decarbonise the iron and so produce a metal more or less analogous to wrought iron and to steel. It cannot be said that this method has solved the problem, because the metal so produced is far from having the qualities which were confidently looked for in the early days of the process. Nevertheless the manufacture of malleable cast iron has received considerable development, especially in substitution for light smithwork, and this is in itself a proof of the difficulty of reaching the desired object by a direct method. It is needless to dwell more particularly on this process, as it will not lead to the solution of the question under consideration.

The methods of overcoming the imperfections in steel castings may be arranged under three heads :—

1. Without altering the system of casting, to limit the ingots to the simplest forms, and to work out the required ultimate shapes by means of hammers, presses, or rolls.

2. To subject the fluid steel, during the process of setting, to heavy pressure ; and by that means to prevent the formation of air-bubbles, and to a great extent also of contraction-cavities. The ingots must still be kept to the simplest forms, and reduced to the required shapes by hammering, pressing, or rolling.

3. To use chemical reagents in order to arrest the formatio
gases, and thus to obtain castings of the most varied forms
dimensions in ordinary sand or metallic moulds.

By the first method the ingot assumes a structure analogou
that represented in Fig. 1, Plate 7; and the defects which arise
between the limits indicated on the upper and lower sides of the fig
The head or top portion of the casting, filled with porosities
cavities, has to be cut off and condemned as scrap. This por
amounts to between one-sixth and one-fourth of the weight of the in
and bears the same relation to it that the head does to an ordinary i
casting. The remainder of the ingot is sent to be worked up in
forge. With the continued increase in the dimensions of guns,
the adoption of steel for the construction of armour plates, the
of steel ingots has also increased; and, as a matter of necessity,
weight and power of the mechanical appliances used for work
them into their ultimate shapes have also been greatly augmen
Accordingly it is found that even 50-ton steam-hammers are
longer powerful enough. At the Paris Exhibition, 1878, the Cre
Works exhibited the full-sized model of an 80-ton hammer the
course of construction, and the model, also full-size, of a 120-
steel ingot. At the works of Saint-Chamond an 80-ton hammer
also in course of erection, and was expected to be finished within
months. For several years past Krupp has talked of startin
100-ton steam-hammer; it is not known however in what state
stupendous project stands at the present time.

In preparing ingots for steel forgings, they are so proportion
with the view of saving as much labour as possible, that the c
section of the casting shall be about double that of the finis
article. With this proportion the outer porous layers of the in
are so far reduced in thickness by forging, that, after removin
comparatively moderate thickness of metal in the lathe or plan
machine, a sound finished surface may be confidently looked
The weight however which is removed by turning or planing, e
under these circumstances, amounts to between 10 and 20 per c
of the finished article; which, added to the head cut off
ingot, represents an important loss of material.

In this system of working it must be borne in mind that the porosity of the inner portions of the ingots, that is the number of local contraction-cavities, is very little reduced in the longitudinal direction; because these cavities do not close, but merely lengthen, in proportion as the surrounding metal is drawn out. In the transverse or radial direction the evil influence of the local cavities is even somewhat augmented; as has been clearly proved by testing the tensile strength of various layers of a thick forged ingot. The following example will illustrate the above statement.

In Fig. 29, Plate 14, is represented, by dotted lines, a cast ingot, the diameter of which is D′. The full lines represent the same ingot, after having been forged under a 50-ton hammer and reduced in diameter to D. After forging, a central hole, of diameter *d*, was bored out, and at *a* seven strips were cut out parallel to the axis of the ingot. Specimens prepared from these strips were tested for tensile strength, and gave the following results for various values of D′, D, and *d* :—

Diameter in inches.			Position of Specimen as numbered on the ingot.	Limit of Elasticity.	Ultimate Strength.	Ultimate Elongation.
D′	D	*d*		Lbs. per sq. in.	Lbs. per sq. in.	Per cent.
47·5	36·5	11	1	26468	77910	16·0
			7	34251	91140	17·0
42·5	32·5	9	2	29106	76440	18·0
			6	36750	94080	16·0
36·5	26·5	8	2	26460	85701	13·7
			5	34986	96138	14·8
36·5	26·5	8	1	27342	66400	16·0
			7	42777	96800	15·0

Inasmuch as the ingots out of which the specimens were taken had all been forged, the question may be asked, whether the superior strength of the outer layers of the material cannot be explained by

the circumstance that they came more immediately under the influence of the hammer. In reply it may be stated that the ingots, after having been forged, were annealed with more or less rapid cooling and that during this operation the various layers were not in an identical condition; but the samples cut out, before being tested were annealed again, under precisely similar circumstances for each pair, and with slow cooling after heating. By this annealing the influence of unequal forging was materially reduced, and therefore the difference of strength must, in a great measure, be referred to local cavities. It is much to be regretted that no opportunity presented itself of making similar experiments on unforged ingots of like dimensions.

To demonstrate the existence of local cavities in forged ingots, it is only necessary to examine Figs. 30 and 31, Plate 14, which show the shape and distribution of local cavities, in forged ingots of similar size and quality with those from which the foregoing specimen strips were taken. The drawings are made half the natural size, from polished strips cut out of forged ingots in the radial direction, as indicated at *b* in Fig. 29. The figures show that forging has caused the cavitiesto elongate in the direction of the axis of the ingot, so as to give them an elliptical shape; and that the number of cavities increases as the centre is approached.

We have next to examine the second method, or that of compression.

The investigation already made into the phenomena accompanying the setting of steel makes it clear that, if it were possible to cast steel under an atmospheric pressure sufficiently great to keep the occluded gases in solution, then the resulting ingot would be perfectly free from gas bubbles. With this view Galy-Cazalat in 1866 proposed to cast steel under the pressure of gunpowder gases, and in France it has been suggested to use steam under a pressure of from 6 to 10 atmospheres. This method is no doubt sound in principle; but it is of little practical value on account of the many inconveniences attending its application, where the character of the products required is so miscellaneous.

Very much simpler is the process of applying pressure through a solid piston, acting on the surface of the freshly cast ingot, and thus producing the so-called "fluid-compressed steel." This system has received some important practical applications, and deserves therefore to be particularly dwelt upon.

The steel is poured into the mould in the ordinary manner, and immediately afterwards its upper surface is pressed by a solid piston, actuated by hydraulic power. The gases which had begun to collect in bubbles on the sides of the mould become reabsorbed under the influence of the pressure, and the cavities are filled with fluid steel, which thus takes the place of the bands of air-bubbles found in other cases. But in order that this absorption of gases out of the bubbles formed along the sides of the mould may take place, it is indispensable that the metal surrounding those cavities should remain fluid, at any rate on one side; in other words, that the pressure should be applied before a thick layer, locking the bubbles in on every side, has had time to form along the surfaces of the mould. With the view of furthering this object, the mould is lined with a refractory and badly-conducting lining. The pressure is usually maintained for a length of time sufficient to enable a thick crust to be formed over the entire surface of the ingot; by this means the escape of the gases is prevented, and these, as has been already pointed out, will by their tension prevent the further evolution of gas in the body of the casting. If this was the only duty the hydraulic press had to perform, one of moderate power would suffice, because it does not require much pressure to stop the evolution of gas. But if it is also intended to do away with the funnel-shaped contraction-cavities, then the press must be much more powerful, in order that the piston may follow the shrinkage of the metal up to the moment when setting takes place in the central portion of the ingot. This is the aim that Sir Joseph Whitworth proposed to himself in constructing his large press, the dimensions of which are truly colossal; for the diameter of the hydraulic cylinder is 50 in., and the water-pressure as high as 5 tons per sq. in., so that the full pressure which may be exerted amounts to 10,000 tons.

It is difficult to say to what degree this press attains the object

of annihilating the cavities in large ingots; for the speci
exhibited by Sir Joseph Whitworth in Paris had a diameter of
12 to 13 in. and a length of 3 to 3½ ft. It was cut in ha
longitudinally, and the cut faces were polished; it was certa
impossible to detect, through the glass case at any rate, the pres
of any contraction-cavities, the ingot appearing to be perfe
solid. The method of pressure however, notwithstanding
many apparent advantages, has not, up to the present time, l
applied to castings of complex form. Besides this it is well kn
that Sir Joseph Whitworth does not content himself with f
pressure only, even for articles of the simplest shape, *e.g.* the ri
of heavy guns, shot, shell, tubes of guns, and the like; but subj
them also to forging, under a hammer or by pressure. Consequ
fluid pressure alone does not solve the problem of bringing s
direct into the various shapes required. It adds indeed to
economy of manufacture and of metal, by doing away with
"head," which has to be sacrificed in the ordinary process, and
reducing to a minimum the allowance for boring, turning, or plan
after forging. But even these advantages are obtained at great c
in the shape of the very large capital necessary for the construc
of the press and its accessories, besides the working expenses, wl
are considerable; and this cost, charged on the comparatively sı
output of a press, is far from being recouped by the saving reali
This is probably the reason why, in western Europe, the adop
of the Whitworth system has been confined to the inventor's
works.

The last method of vanquishing the difficulties surrounding
steel founder is distinguished from the others in that it comple
solves the question, and is based on scientific research.

A partial success, in the harder kinds of steel, was obta
more than twenty years ago, by Mayer, at the Bochum works;
his method was adopted by several German, Austrian, and Eng
factories. As examples of this process, the Bochum bells, of w
some 3,000 have been made up to this time, are especially fam
and various other castings, such as wagon and locomotive wh

crossings, sundry ironwork connected with railways, screw propellers, cylinders for steam engines and hydraulic presses, toothed wheels, &c., have been turned out with success.

All the above articles are cast in sand moulds, out of steel comparatively hard and rich in carbon, melted in crucibles; each charge having added to it a considerable quantity of siliceous pig-iron, which imparts to the metal from 0·3 to 0·4 per cent. of silicon. As soon as this method, which was at first kept secret by the works where it was adopted, became more generally known, it fell under the scrutiny of scientific metallurgists, and it was soon found that the soundness of the castings was due to the presence of silicon in the steel, and that this substance acted in a twofold manner. On the one hand it materially diminished the solubility of gases in steel during the melting of the metal, and on the other it impeded the formation of carbonic oxide, a formation due to the reaction of the oxygen, which is dissolved in the steel during melting, on the oxide of iron and the carbon.

Inasmuch as melting in closed crucibles protects the metal in a great measure from the oxidising effects of the atmosphere, and at the same time the greater proportion of carbon in hard steel makes the latter less liable to dissolve the oxides of iron, the production of sound castings from the crucible is less difficult than when soft Bessemer or Siemens-Martin steels are used. At the present time however, judging from their display at the Paris Exhibition, the Terre-Noire works have overcome the last difficulties surrounding the art of producing perfect steel castings.

In order to obtain mild steel from the Bessemer converter or the Siemens-Martin furnace, it is well known that it is necessary, at the close of the operation, to add considerable quantities of manganese, in order to reduce the oxide of iron dissolved in the fluid metal. Spiegeleisen is employed for this purpose, on account of the large quantity of manganese it contains; and, for very mild qualities of steel, the so-called "ferro-manganese" is used. This has a similar composition to spiegeleisen, that is, iron, carbon, and manganese; but the proportion of the latter is so large that the fracture of the metal no longer presents the large mirror-like facets which characterise spiegeleisen.

The honour of introducing the use of mixtures of iron be a very high proportion of manganese, reaching even to 80 85 per cent., belongs to the engineers of the Terre-Noire w under the management of M. Euverte; and to them also mu ascribed the credit of adding a large quantity of silicon, and achieving the important end of obtaining sound castings out of Siemens-Martin or Bessemer steel. It is well known that i Bessemer converter, as well as in the furnaces of Martin and P the silicon, which is contained in the fluid metal at the beginni the process, nearly all becomes oxidised, and disappears in the the exception being when the Bessemer process is carried c a very high temperature, and with pig-iron containing a percentage of silicon. It happens therefore that at the end o process the metal is generally free from silicon; and as n spiegeleisen nor ferro-manganese contain much silicon, it result the steel, after the addition of either of those two substances, is little richer in silicon than before. This is the reason why Bessemer and Siemens-Martin steel hold large quantities of and oxides in solution, and why castings made from them are gene permeated with gas-bubbles. The ferro-manganese-silicon mel now produced at Terre-Noire, furnish the means of introducing the final product of the Bessemer or Siemens-Martin process quantities of silicon as are indispensable for the perfect decompo of the carbonic oxide dissolved in the metal; and for the form of a double silicate of iron and manganese, during the reducti the iron oxides which are also dissolved in the steel. This d silicate, being very buoyant and fluid, rises with comparative fre to the surface; and in this manner very effectually clear metallic bath of the finely-divided slags, which exercise a perni influence on the mechanical properties of the steel produced.

According to M. Pourcel, the new mixture is added a end of the process, before casting, and in such quantities tha cast metal should contain 0·2 to 0·3 per cent. of silicon. In ord neutralise the pernicious influence of silica on the stability o union between the iron and the carbon, it is necessary to intr

such a quantity of manganese that the proportion between the silicon and the manganese should be as 2 to 3.*

Steel produced under these conditions pours into the moulds quickly without boiling up, and produces castings free from bubbles. To reduce contraction-cavities, heads are used as in iron castings. The splendid collection of cast-steel articles, shown by the Terre-Noire works, proves that the problem of obtaining the most complex forms of steel by direct casting into moulds is now very near its complete solution.

Even if it cannot be said that the difficulties surrounding the production of perfectly sound castings out of *pure steel* have been completely vanquished, yet it is fit that full recognition be made of the services rendered by the Terre-Noire works in preparing, by rational and scientific investigation, a way to the desired end. It may now be said that the veil has at last been lifted, which concealed so long from the eyes of numerous investigators the cause of the porosity of steel castings. It remains still to discover how to reduce the addition of silica to a minimum, in order to avoid, as much as possible, the use of manganese, which is necessary to neutralise the action of silica in withdrawing the carbon from its union with the iron. No less important are the investigations of Pourcel on the fluidity and subsidence of the silicates produced by the addition of ferro-manganese, at the end of the conversion, in the manufacture of Siemens-Martin and Bessemer steel.

Among the castings exhibited by the Terre-Noire factory, the following claim special notice.

(1.) Two shots of 0·32 m. ($12\frac{3}{4}$ in.) diam. and 0·786 m. ($30\frac{1}{4}$ in.)

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* It is assumed that silicon possesses the property of separating carbon, in the form of graphite, from its combination with iron. The experiments of Caron have shown that if steel, rich in carbon and also containing much silicon, is heated frequently and for a long time, without being forged, or is repeatedly annealed, it deteriorates greatly, because nearly the whole of the carbon becomes separated in the form of graphite. Manganese, by combining with the silicon, prevents this action taking place; and hence, in the best Sheffield steel, the presence of manganese is considered an indication of superior quality, although it would be utterly useless but for the occurrence of silicon.

length, which had passed through iron armour 0·30 m. (11¾ thick, backed by 1 m. (3 ft. 3⅜ in.) of timber. The shots struck target at an angle of 20° and remained uninjured, with the excep of a slight deformation of the heads, by which the projectiles v shortened by from 14 to 19 mm. (0·55 to 0·75 in.), the diame were increased by 0·5 mm. (0·02 in.), and the points were defle 17·5 to 27 mm. (0·68 to 1·05 in.) from the axis.

(2.) The inner tube for a 14-centimetre (5½ in.) naval gun. T tube had been tested by a committee on naval artillery experim at Ruelle. One hundred rounds had been fired, commencing v charges of 4·2 kg. (9·3 lb.) of powder and 18·65 kg. (41·1 lb.) of s and ending with 4·9 kg. (10·8 lb.) of powder and 21 kg. (46·3 lb. shot. The deformation proved to be somewhat less than with for steel tubes tested under like conditions.

(3.) An experimental tube that had stood the powder test Bourges.

(4.) A rough turned ingot for a 24-centimetre (9½ in.) g weight 11½ tons.

(5.) Inner tubes for guns of 24- and 32-centimetre (9½ in. 12¾ in.) calibre, and a trunnion ring for a 42-centimetre (16½ gun, weighing 6½ tons; a crank for a steam engine of 400 H a locomotive crank-axle, and so forth.

The finish of all these articles would compare favourably v that of the best iron castings. In the thicker ingots however, especially in the central parts, the fractures showed, scattered l and there, those local contraction-cavities which have already l minutely described.

On examining the region of bubbles entangled in the central p of steel ingots, it will be seen that in most cases the lower half c bubble has a more or less smooth hemispherical form, while the si and especially the upper portions, are covered with arborescent grow of the most varied forms, as shown magnified in Fig. 32, Plate 14. carefully comparing these arborescences with the discontinuous crys of the contraction-cavities, it will be noticed that a similarity ex between them, and that the arborescences are in fact formed from

crystals encountered by the bubble in its upward movement, at a time when the steel has so far set, that is, has become so far filled with discontinuous crystals, that the bubble cannot freely rise to the surface. As the bubble floats upwards, motion of the surrounding fluid takes place; the floating crystals are moved aside and turned over, and as they are at the same temperature as the surrounding fluid, they are very tender, and apt, on the least provocation, to dissolve again. Consequently, during the passage of a bubble, the crystals are partly dissolved and partly transformed; they interlock with each other and form arborescences of the most complicated shapes, so much so that it is frequently impossible to find any likeness to the discontinuous crystals from which they were originally produced. This may be seen in Figs. 33 and 34, Plate 14, the latter representing one of the arborescences detached and magnified 80 times.

From what has been said above it is evident that in order to destroy the discontinuous crystals which are constantly forming, in other words to effect their complete solution in the surrounding fluid mass, it is sufficient to give to that mass a comparatively slow movement, seeing that the motion of the gas bubbles alone is almost enough to accomplish the same object. This circumstance leads to the conclusion that it is possible to prevent the acicular formation of the outer layers of ingots cast in iron moulds, as well as to obliterate the local cavities or porosities of the central portions.

In fact, if, during the pouring of an ingot, the mould were caused to rotate with considerable velocity, then the discontinuous crystals tending to form at right angles to the sides would not be in a condition to develop so rapidly as if the mould were at rest; and the steel would set in smooth layers of amorphous structure. If the rotation is continued till the central core of the ingot has set, then the whole mass will present a uniform structure, and all causes for the formation of local cavities will cease. The casting will be perfectly sound throughout, and will not require to be consolidated either by hammering or by pressure. It will be sufficient to anneal the ingot, in order to destroy the coarsely crystalline formation which the metal receives after it has set, during the slow subsequent

cooling. Inasmuch as in the beginning of the pouring, in conseque of the powerful cooling action of the mould, the crystals grow v rapidly, it is necessary that the rotation of the mould should rapid; but as the friction between the sides of the mould and fluid steel will cause the latter also to revolve, it will be necess from time to time to alter the direction of rotation, in other wo to cause the revolution to take place in alternate directions tolerably short intervals.

For cylindrical ingots in which an axial bore is afterwards to made, such, for example, as those prepared for the manufacture breech-loading guns, it would be more convenient to cause the mo to revolve on a horizontal axis, and with this object to turn it on side, as soon as the crust over the upper open end had form The contraction-cavity would then be distributed evenly along whole length of the axis, instead of forming a funnel at one end; there would be no need to add any considerable head of me For shell, when unforged, and cast at once to the finished form, at Terre-Noire, the rotation would answer best on an inclined a since it would then tend to produce a long funnel-shaped cavi very nearly of the shape required. It is impossible not to ad that the constant mixture of the metal during rotation will tend create uniformity of structure and prevent liquation.

The above description brings to mind the so-called "centrifu system" of casting, but the similarity is superficial only. Up to present time the idea of centrifugal casting implies the developm and use of centrifugal force in order to consolidate the metal i radial direction; as for example in the tread of a cast-iron wa wheel. If it is really a fact that, with the centrifugal method casting, the iron becomes more sound and compact, then this ef must not be ascribed to centrifugal force, but only to the circumsta that the motion produced in the liquid metal hinders the formatio discontinuous crystals. It is highly probable that the use of t process would very greatly improve the qualities of chilled cast-i rolls, of cast-iron ordnance and projectiles, and of some kinds of b castings.

There still remains one question to discuss—a question which has already been considered in the author's paper of ten years ago, on the Manufacture of Steel—namely whether forging is necessary to steel, even when cast perfectly sound, without bubbles or local contraction-cavities. To answer this question it would be sufficient to refer to the experiments made in 1869 by a Committee of the Technical Society (see their Proceedings, 1870, second issue); but several new facts are available, and these are embodied in Tables I. and II. appended.

A comparison of the figures in these two Tables shows the uselessness of any kind of pressure or forging to improve the mechanical properties of steel. The whole question lies in the skill of the founder. The low mechanical properties which distinguish unannealed cast steel, whether compressed or not, from annealed or forged steel, can be explained by its coarsely crystalline structure, by the presence of local cavities, and especially by granulation. This latter defect is only partially removed by annealing, which may be explained by the circumstances that the surfaces of contact of the grains are separated by varying distances; and that these distances always exceed the limits within which cohesion acts at ordinary temperatures, but not, in general, its limits at a bright red heat. If these latter limits are not exceeded, then, when the steel is heated for annealing purposes, the grains stick together. It happens most frequently that only some of the grains adhere to each other, those namely which are not separated beyond the limits of cohesion at a high temperature, while the remainder do not unite. In this manner, in most cases, granulation is only lessened, and not entirely destroyed, by annealing.

Granulation is further developed by the tension produced during the cooling of the castings, and while they are still at a red heat. The outer layers are brought into a state of tension at the commencement of cooling, and the inner ones towards the end. In this respect Sir Joseph Whitworth's method of casting with an internal core is objectionable; the core hinders the free contraction of the annular-shaped casting, causes the metal to stretch, and so favours the development of granulation. This is the reason why

strongly compressed steel in the form of annular ingots] comparatively low tensile strength, even after having been anneal It is well known that Sir Joseph Whitworth forges or otherw works his steel after pressing; and a comparison of Tables I. and demonstrates that it is only after forging that annular-sha compressed steel can compare in mechanical properties with the and annealed steel of the Terre-Noire works.

It may here be noted that Sir Joseph Whitworth's results s remarkably great elongation in his steel before rupture; but it sh be borne in mind that his samples were only 2 inches long, while other makers make use of specimens 8 inches long, which only about half the proportionate extension under tensile tests.

The conclusion to be drawn from what has now been discusse the following.

The problem of preparing sound castings, direct from the mo may be considered solved as far as the absence of gas-bubble concerned; and this is the point of cardinal importance, whether result be obtained by the high temperature at which the meta poured, by the use of silicon, or by subjecting the casting to mode pressure, say six to ten atmospheres. To give the steel so obta its best internal structure, and the necessary mechanical proper it is sufficient to anneal it, with a more or less rapid cooling tempering.

Special attention in casting has to be devoted to the suppres of contraction-cavities and granulations, whether grain-like prismatic in form. These can be prevented, as has been shown proper methods; among the best of which is that of keeping motion in the melted steel which is in contact with the solidi layers. Granulations will be avoided by the use of sand, or ot non-conducting, moulds, by letting the castings cool slowly, and removing all obstacles to the free contraction of all the parts of casting. The same precautions will prevent the formation of cra

For the most simple forms these requirements are most rea met—and that without necessitating a high temperature in the me

which is specially important with respect to granulation—by the use of substantial cast-iron moulds, thickly perforated with holes, and protected by a fire-resisting lining of moderate thickness.

The compression of fluid steel by means of a solid piston appears to be applicable only to the simplest forms, and to have no real future before it. The hammer and the rolls would still be necessary for the production of such ordinary shapes as cannot by casting be produced sound and with a smooth skin.

TABLE I.

Experiments on the Tensile Strength of Steel at the Terre-Noire Works.

Diameter of Specimens, 14 *mm.* (0·55 *in.*)
Length of Specimens, 100 *mm.* (3·93 *in.*)

Nature of Specimens.	No. of Specimen.	Percentage of Carbon. Per cent.	Elastic Limit. Tons per sq. in.	Ultimate Strength. Tons per sq. in.
Forged Steel. (Containing about ½ per cent. of manganese and a trace of silicon.)	1	0·150	13·70	22·24
	2	0·490	16·32	30·40
	3	0·709	19·69	42·36
	4	0·875	21·31	46·16
The same after annealing in oil. (Composition as above.)	5	0·150	20·43	28·16
	6	0·490	27·79	43·92
	7	0·709	42·86	66·72
	8	0·875	56·38	66·14
Cast Steel not Forged. (Containing about ⅔ per cent. of manganese and ⅓ per cent. of silicon.)	9	0·267	13·08	27·85
	10	0·459	16·51	26·98
	11	0·750	19·00	40·00
	12	0·875	24·42	40·18
The same after annealing in oil and tempering. (Composition as above.)	13	0·267	19·69	32·27
	14	0·459	20·87	34·58
	15	0·750	22·30	46·23
	16	0·875	28·66	51·46

TABLE II.

[E]XPERIMENTS ON THE TENSILE STRENGTH OF STEEL AT THE ABOUCHOFF WORKS.

Diameter of Specimens, 12·5 *mm.* (0·49 *in.*)
[L]ength from 150 *mm. to* 250 *mm.* (5·91 *to* 9·84 *in.*)

[S]pecimens.	Elastic Limit. Tons per sq. in.	Ultimate Strength. Tons per sq. in.	Final Extension. Per cent.	Remarks; and Percentages of Carbon, Silicon, and Manganese.
...-in. Bes... teel shot, ...6 Abou... [wo]rks; not ...nor an... . .	16·38	39·37	4·0	Mean of two analyses. C = 0·70; Si = 0·07; Mn = 0·54.
...aled .	24·93	46·59	8·0	
Bessemer ..., No. 1095 ...d sample	17·71 18·43	39·37 40·02	16·5 15·5	C = 0·43; Si = 0·04; Mn = 0·30.
annealed ...r steel, ...s of 9 in. ...result of ...nples) .	16·40 to 18·37	42·65 to 48·55	20·0 to 14·0	C = 0·35; Si = 0·01; Mn = 0·12; to C = 0·45; Si = 0·10; Mn = 0·30.
...in. shot of ...manufac... . .	..	45·27	10·0	C = 0·68; Si = 0·23; Mn = 0·29.
annealed ... of Terre... ...ke .	24·93 to 26·24	46·59 to 53·15	3·4 to 5·6	C = 0·57; Si = 0·24; Mn = 0·29.
annealed ...t, Imca... ...ks .	36·74	36·74	0·4	C = 0·72; Si = 0·22; Mn = 0 61.
...mpressed pressure ...00 atm.; ...ut further ...g . .	18·59	30·61	2·4	Crucible steel containing about C = 0·54. Mean of 6 specimens.
...aled .	20·83	34·61	6·7	" " 4 "
...d and an... . .	*21·00	42·00	16·0	" " 2 "
...mpressed ...essure of ...00 atm.; and an... . .	17·30	32·15	18·1	" " 2 "

Institution of Mechanical Engineers.

PROCEEDINGS.

April 1880.

Spring Meeting of the Institution was held at the Institution Engineers, London, on Thursday, 22nd April, 1880, at half-n o'clock, p.m.; Edward A. Cowper, Esq., President, in the

Minutes of the last Meeting were read, approved, and

President announced that the Ballot Lists for the election Members had been opened by a Committee of the Council, t the following candidates had been found to be duly

MEMBERS.

Anderson,	Mouram, Russia.
t Baillie,	London.
am Neish Bain,	Hong Kong, China.
nder Borodine,	Kieff, Russia.
s Robert Fountaine Brown,	Montreal, Canada.
s Merson Davies,	Klumdna, India.
am. Alfred Harry de Pape,	Tottenham.
Farcot,	St. Ouen, France.
am Bernard Godfrey,	London.
son Hayter,	London.
Humphrys,	Barrow-in-Furness.
Joy,	London.
l Longworth,	London.
t Frewen Martin,	Loughborough.

Richard Moreland, Jun., ...	London.
James Courthope Peache, . . .	Crewe.
James Stirling, ...	Ashford.

ASSOCIATE.

William Edgar Allen, . . .	Sheffield.

GRADUATES.

Edward William Anderson, . . .	London.
William Henry Ray Buckle, . .	Newcastle-on-'
Archibald Adley Francis, . . .	London.
Francis Marten Weymouth, . .	London.
Francis Colin York, ...	Wolverhampto

The President announced that a legacy of £100 had presented to the Institution by the executors of the late Mr.] Napier, Past-President, being part of a sum of money left b to be divided amongst scientific institutions, at the discret his executors. The Council had resolved that this money sho laid out in the purchase of books, which were very much requi the library. The books would be kept separate from the ı the library, as the bequest of Mr. Napier. In furtherance same object, a list had been made out, of books which it was de to add to the library, and that list would be circulated amo Members, some of whom might be willing to make contributi spare copies from their own stock, or might suggest wher could be obtained.

The President announced that the Research Commit Riveted Joints were now carrying on their experiments, for Professor Kennedy, of University College, had kindly offe use of his testing machine gratuitously: and on the fol morning any Member of the Institution could have the oppo of witnessing the experiments in progress.

The President announced that the Summer Meeting would be held at Barrow-in-Furness. There would be meetings for the reading of papers on the 3rd, 4th, and 5th of August, and probably excursions on the 6th and 7th.

The following paper was then read:—

ON PERMANENT WAY FOR STREET TRAMWAYS, WITH SPECIAL REFERENCE TO STEAM TRACTION.

By Mr. J. D. LARSEN, of London.

If we dismiss from consideration Mr. Train's attempts in 1861, the failure of which arose from the unsuitable section of rail adopted, we may fairly say that the introduction of Street Tramways, so far as London is concerned, dates only from 1869. In that year three lines were authorised, viz. (1) the North Metropolitan Tramways embracing the Whitechapel, Mile End, and Bow roads; (2) the Metropolitan Street Tramways, for the Kennington, Brixton, and Clapham routes; and (3) the Pimlico, Peckham, and Greenwich Tramways, from Pimlico to Greenwich. The two latter companies, which had powers over some 25 miles of streets, have since been amalgamated, and are now known under the title of the London Tramways Company.

Some idea of the success of tramways, and of the increasing estimation in which they are held by the public, may be formed from the fact that in nine years, up to 30th June 1878, there had been authorised by Parliament no less than 65 miles 58 chains of line, of which 56 miles 50 chains were completed and open for public traffic. The greater portion of this was double line; turned into length of single line it gives 124 miles 46 chains authorised, and 107 miles 29 chains finished. These lines, necessitating a paid-up capital of as much as £1,326,054, refer to the metropolitan district only.

The growth of the system has been no less widely developed in the provinces. The total mileage of road for the United Kingdom was

at the same date 346½ miles authorised, and nearly 269 miles finished and in use. This, turned as before into length of single line, gives 526½ miles, and 408½ miles respectively, with a paid-up capital of £4,035,464.

The extensive patronage which tramways receive from the public (nearly 150 millions of passengers being carried annually) is by no means due to the superior accommodation of the vehicles, as is evidenced by the fact that the business of the London General Omnibus Company, contrary to all expectation, is not adversely affected by them. In the author's opinion their success is mainly due to the reduction in fares, and to the increased service, these two innovations having been sufficient to create a traffic which before was non-existent.

Street tramways are now so firmly established, and have proved so great a boon to the masses, that the opponents to the system, on the score of its spoiling the roads, are daily being ousted from their position. Any improvements in the facilities for intercommunication in large towns are of such vital importance to the industries which have created such towns, that the opposition of the few must inevitably succumb to the rapidly increasing wants of the many.

The objections to a tramway on a public highway are being grappled with and overcome one by one as experience is gained; and if ten years hence the best constructed tramway is as far superior to the best of the present day as this latter is to the original road of ten or more years ago, we shall have so far progressed that opposition on the ground of interference with other interests will not be tenable.

The author's present object is to point out some of the defects in the different systems of permanent way for tramways, and some of the steps that have been taken to overcome them. It may be observed at starting that many lines in this and other countries have been unfairly handicapped, by being called upon for duties they were never designed or constructed to perform, notably in the matter of steam traction in lieu of horse-power. Here, in addition to the rails having to carry perhaps three times the load originally intended, all the tractive force is transferred from the roadway to the rails; and

when it is considered that this is an entirely new and very heavy du which these lines were never expected to perform, the only mat for surprise is that they should have stood so well. A tramway th would serve admirably for heavy horse traffic, might be so construct that to use steam traction on it would be to destroy it immediate An illustration may be found in the original way or track laid f the running of coal-wagons, otherwise trams, whence the derivati of the word "tramway." These tracks were made, and are so st in some places abroad, of hard wood scantling, about 4 in. squa faced with light flat bar iron spiked on. These do good service w horse or mule traction; but to transfer the tractive force from t road to the rails themselves would ensure their total failure.

Early Systems of Laying Tramways.—The first form of rail used London is shown in Fig. 2, Plate 15; it is the same as had previou been used in Liverpool and Birkenhead by Mr. George Hopki The method of construction was also the same, except that London trenches for concrete, about 9 in. deep, were dug under t longitudinal sleepers, as shown in Fig. 1. The Whitechapel sect of the North Metropolitan Company, and the Brixton section of t London Tramways Company, were laid in this manner. The ra weighed 45 to 48 lbs. per yard, and were spiked to the longitudi sleepers by vertical spikes, through countersunk holes made in t bottom of the groove. The longitudinals were laid in cast-i chairs, or shoes; and the gauge was secured by $1\frac{1}{2}$ in. $\times$ $\frac{3}{8}$ in. i tie-rods, the ends of which were upset of a dovetail form, as shown Fig. 3, and dropped into sockets of corresponding shape, cast on shoes. There were many objections to these tie-rods: in the f place, the slightest variation in the angle of the bevelled ends, o the sockets, would affect the gauge; in the next place, after the r was finished the tie-rods would occasionally work up above surface of the stones; and last, but not least, in some instance was found that when the pavior came upon a rod that did not conveniently for a joint in the paving, he would, if he had opportunity, solve the difficulty by lifting it out, dropping it into bottom of the trench, and paving over it, in which position it

possibly quite as useful as in any other. In the reconstruction of some of the North Metropolitan lines in 1877, the tie-bar shown in Fig. 4, Plate 15, was substituted, which did away with many objections to the former system. In some places the author has used the forms of tie-rods shown in Figs. 5 and 6, that in Fig. 5 having a cottered end, and that in Fig. 6 being simply split, turned back, and punched for the nails. Where however the rail is mounted on a longitudinal timber sleeper of a width not exceeding the rail, transverse sleepers should be used if possible instead of ties. At the same time it would be bad policy in dealing with a road previously paved, and where the substratum under the setts is in good condition, to destroy this for the purpose of putting in cross sleepers; and as a matter of fact it will generally be found that the municipal authorities will not allow it to be done. In all such cases the best practice is to increase the base of the longitudinal sleeper.

The original method of securing the rail to the sleeper, as shown in Fig. 2, Plate 15, was also very objectionable. The vertical countersunk-headed spikes were apt to work loose, and the water, percolating through the hole in the rail, so softened the timber round the spike that it had no hold. In some instances the heads of the spikes would fly off, probably quite as much from the percussive action of the ordinary road traffic as from that of the tramcars. From these causes the vertical spike fastening proved wholly inadequate as an effective method of securing the rails; on lines so laid, after a few months' work, loose rails were the rule and not the exception. Irrespective of the defect itself, this in wet weather formed so great an eyesore that it was an unanswerable argument in the hands of the opponents to tramway extension. Each passing vehicle created a continuous line of little mud fountains, bespattering the adjacent roadway and everything near it with slush and filth, while this same action was rapidly destroying the foundation and substructure.

Again it will be seen that this section of rail, Fig. 2, is practically a flat bar of iron with a groove rolled in it near one edge; its inherent weakness under a load will thus be evident. To obviate this defect the author had rails rolled with flanges about ½ in. in depth

depending from the under side of the rail on each side. T
made a considerably stronger rail without increasing the secti
area; and with this section the first portions of the Pimlico, Peckl
and Greenwich, and also of the London Streets Tramways,
laid. One part of these was laid with 60 lb. and another
with 50 lb. rails, the two sections being as shown in Figs. 7 an
Plate 15. The author then proposed to deepen the flanges
further, but was met by the assertion that it was not possibl
rolling the rails to get the metal down to fill so narrow a fla
By degrees however they were deepened to 1 inch, and ultimatel
$1\frac{1}{8}$ in. and $1\frac{1}{4}$ in., a large delivery of these latter being accompa
by an intimation that the author could have them rolled to any d
he chose. The North Metropolitan Company are now using a
with flanges full $1\frac{1}{2}$ in. deep on either side, as shown in Fig. 9.

As soon as rails were obtained with depending flanges an inc
depth, the author commenced the use of side fasteners, attaching
rail to the sleeper in the manner shown in Figs. 10 and 11, Plate
which are an elevation and section of what have since become kn
as "Larsen's rails and side fasteners." This system was brought
in 1871, and from that time has been the method of attachn
universally used for this section of rail when mounted on w
sleepers, and in some instances when mounted on iron sleepers
The flanges are rolled of a sufficient depth to enable holes to
pierced through them below the upper surface of the sleeper.
sleeper is rabbeted down on its upper edge, to fit accurately the u
side of the rail, and the latter is then secured to it by means
half staple. Of this the portion A, passing through the rail fla
into the sleeper, is round, while the other part B, lying against
rail and sleeper, is flat, of say $\frac{3}{4}$ in. $\times$ $\frac{5}{16}$ in. section, and has a h
or holes punched in the end, for a nail or nails as may be desired

The introduction of this rail and fastener abolished comple
the old form of rail with vertical spikes, and proved a mar
improvement over former practice. The greater portion of
London Streets Tramways, and of the Pimlico, Peckham,
Greenwich Tramways, were laid by the author on this method.

This fastener has no tendency to draw the rail and sleeper

close contact. The author therefore designed a screw cramp, Fig. 12, Plate 16, to hold the rail and sleeper together while fixing the side fasteners; and found that with the aid of this tool a very sound and close attachment of rail and sleeper was obtainable. This tool was first used on the Greenwich lines, but so universally has it come into use that it may be seen wherever a tramway is being constructed or repaired.

Since these side fasteners were first introduced, many modifications of them have been attempted. Figs. 13 and 14, Plate 15, represent a form designed by Mr. H. T. McNeale, and used at Rouen. The author considers this form a good one; but, unless considerable play be allowed to the pins of the fastener within the holes in the rails, trouble will be caused by the expansion and contraction of the rails under varying temperatures.

The greater portion of the Pimlico, Peckham, and Greenwich lines were laid with transverse sleepers of the same section as the longitudinals—4 in. by 6 in.—laid on the flat and secured to the longitudinal sleeper by means of brackets, as shown in Fig. 15, Plate 16. The principal objection to these brackets is that they necessitate the cutting back of the side of the paving stones wherever they occur, to enable the upper surface of the stone to come close up to the rail. Hence the stone is more or less pyramidal in form, and, standing on its apex, is very liable to rock; the result is that every here and there there is a loose stone adjoining the rail, giving an unsightly appearance to the road, and admitting water to percolate through to the foundation.

In Paris the author laid some miles of rail to the section in Fig. 16, which is still weaker than Fig. 2, and perhaps the worst section he has ever seen. By persistently advocating a change, he ultimately induced the municipal authorities to use a rail of the section shown in Fig. 17; and these, in steel, are the rails now in use. It would scarcely be supposed that the section in Fig. 16 would have been adopted after the section in Figs. 10 and 11 had actually been in use; but so it is, and the former section is even now down on one road, where steam traction is used. While such is the case, but little surprise need be felt if bad accounts of the

success of steam power reach us from Paris. In this instance so at least, if not all, of the blame may be laid to the permane way. Even the section of steel rail, Fig. 17, is light to r locomotives over; but the author was limited to 42 lbs. per me run.

One unavoidable element of weakness, on every road along whi a tramway runs, lies in the fact that there is everywhere a continu unbroken joint between the rail and the pitching, lying in a li with all the traffic of the highway. This has been the cause of c of the most irritating inconveniencies yet met with in connecti with street tramways, so far as they affect the ordinary traffic of t road. In spite of the greatest care in paving, the stones immediat adjoining the rail sink in places, allowing the rail to peep up ab the surface of the road. Now the slight sinking of one or a do stones from their normal level, in the middle of a wide paved str is in itself of comparatively little moment, and would only sl a slight depression in wet weather; but when a straight and le iron rail runs through the centre of such a depression, ev carriage or vehicle crossing the spot, at any angle short of a ri angle, will be most unpleasantly skidded or slung more or less of its course. This occurs, however small the difference betw the level of rail and stones may be, a quarter of an inch be quite sufficient to constitute a grave fault.

Larsen's improved System for Steam Traction.—The time now come when tramways about to be constructed will have t designed for the possible contingency of using steam traction them, even where at present its use may not be contemplated.

In view of this necessity the author in his latest practice adopted the system of construction shown in Figs. 18 and 19, Plate which are an elevation and section of a rail and of a continuous wrou iron girder sleeper. The rail A is of the ordinary section kn as Larsen's rail, the side flanges being punched precisely as w first introduced for use with timber sleepers. This rail is sec to the top of the sleeper by a side fastener in the form of a hook- B, having one end simply turned over at a right angle, and

other end screwed for a nut. Between the web of the rail and the central web of the sleeper there is a filling piece of cast iron I, made with a slot or groove down its outer side, in which the hook-bolt lies. The hook-bolt is first inserted through the rail flange from the inside; this filling piece is then slipped up behind it, and a lock nut screwed on; and the rail is thus secured to the girder in a manner as rapid and easy of accomplishment as it is secure and effective.

The base-plate D may be made as wide as desired; but by making it wide enough to form a good broken joint with the first paving sett, ample base area will be secured for the stability of the tramway rail, being in fact nearly three times that of the earlier systems. The continuity of the rail and sleeper is secured by making rail, sleeper, and base-plate all break joint. Fish-plates are unnecessary, inasmuch as the base-plate forms an effective fish-plate for the girder sleeper, and this again for the rail; so that, due attention being given in first construction, a faulty or loose joint is impossible, unless the rail, girder, and base-plate should all be broken completely through. Loose joints at the ends of rails are common faults with the light sections used in Paris, and are due to the difficulty in fishing, and also to the fact of there being no concrete substratum.

It will be seen by Fig. 19 that the paving, or road metalling, can be laid close to the rail throughout the whole length, there being no projection, however trifling, such as exists in the case where shoes or brackets are used. The advantage derived from having nothing projecting outside the rail is a substantial one; the evils resulting from having to cut the under side of the stones have already been noticed, and are also dwelt upon by Mr. Robinson Souttar in a paper read before the Institution of Civil Engineers (Proceedings, vol. L., p. 4) when criticising the author's side fasteners and the method of securing them. Mr. Souttar proposes to remedy this defect by having the rail rolled with the flanges set back towards the centre $\frac{3}{8}$ in. on each side, or by a distance equal to the thickness of the side fastener. This method however practically makes the under side of the rail $\frac{3}{4}$ in. less in width than the top. Now although it is very possible that this would make no great difference to the stability of the rail,

nevertheless it is at least a step in the wrong direction. removing one evil by substituting another, perhaps a little objectionable. Other conditions remaining equal, if the base o rail could be made $\frac{3}{4}$ in. wider than the top, a decided adva would be gained.

The wide base-plate in the author's system keeps the p alongside the rail quite sound, and prevents that deposit of and slush which is now so commonly seen on either side o rail, and which is continually working down, and rotting or inju the foundation of the road. Between the rail and sleeper a of tarred felt or similar material is inserted throughout the w length, to give a little elasticity, and make a good joint. bearing against iron is always objectionable, unless the piece riveted together, as in the case of the base-plate.

In the author's opinion the arguments used in support timber longitudinal sleeper, on account of its superior elast rest upon wrong premises. It has often been urged tha experience with railways has proved the superiority of an el over a non-elastic road, and that a tramway being really a rail the same necessity exists. A moment's consideration will show absurdity of the comparison. A railroad has frequently an e weighing 30 to 40 tons dashing over it at 50 or more miles per h while an excessive weight and speed on a tramway would tons and 8 miles per hour. Now assume the case of a compl non-elastic road, and on it a sharp inequality, such for instan would be produced by the end of a rail being packed up above the adjoining rail. Then the heavy and fast engine either beat down the obstruction at one blow, or else would clean off the rails; while the light and slow engine would p with a slight shock or jolt and nothing more. The author hol the contrary that a tramway should be more rigid than a rai for the reason that it should approximate, as nearly as may the condition of the highway adjoining it.

The author's system is particularly adapted for steam tracti the girder sleeper most effectually fishes the rails, and a good ju of rail to rail is a *sine quâ non* for any mechanical meth

haulage. With the section of rail under consideration, and with timber sleepers, a good fishing of the rail-ends is not easily accomplished; and this is one of the weak points in most existing lines. The advantage of having no perishable material buried underground is so evident as to require no comment. When the rails require renewing, they alone will need to be disturbed; the concrete, if good when first laid, will be better twenty years afterwards.

Figs. 20 and 21, Plate 16, show other rails and sleepers, differing in section, fastenings, &c., but each embodying the same system of construction, namely a continuous rail and a wrought-iron or steel girder sleeper, with wide base-plate extending underneath the adjoining paving.

Barker's System.—Figs. 22 and 23, Plate 17, represent the system of tramway construction introduced by Mr. B. Barker. This, like the author's, has an extended base beneath the adjoining paving, but the sleepers are of cast iron and are necessarily in shorter lengths. They are specified to be "of such lengths compared with the lengths of the wrought-iron or steel rails as will ensure the joint in the rails always occurring in one of the castings. Thus if all the castings are three feet in length, the rails may be nine, twelve, fifteen, eighteen, twenty-one and twenty-four feet in length, and in this case a rail joint will always occur in the centre of a casting." By this it appears that three feet is considered a convenient length for the sleepers, and this would especially be the case on curves, since separate castings would otherwise have to be made for each radius. The use of cast iron, and the necessarily short lengths, are the only apparent objections to this otherwise excellent system.

The section, Fig. 23, shows the method of securing the rail to the sleeper. The taper key or cotter C passes through a hole cast in the sleeper, and through a corresponding hole in the central web of the rail.

Gowan's System.—Figs. 24 and 25, Plate 17, show Mr. Gowan's system. This consists of a simple flat-bottomed rail, with the web deep enough for the foot or base to reach below the paving, and with this foot rolled wide enough to constitute a foundation for the concrete or

paving setts on either side of the rail. The web is perforate intervals, Fig. 24, which, in the case of a tramway laid in cemen concrete, enables the cement or concrete to be filled into the openi thereby binding the whole together, and keeping the rails bot line and level. No method of fishing is shown, as it is obvious with this section a most perfect junction of rail to rail can be e obtained. Mr. Gowan describes several methods. The only app objections to this system are the great first cost, due to the difficu of manufacture, and the fact that when the rail surface is worn the whole requires renewing. The rails seen by the author had grooves planed out of the solid, and the perforations through the drilled out; consequently the cost for labour in manufacture c not but be large. With regard to the second objection, not must the whole substructure be renewed, but the taking i necessitates the disturbance of the concrete foundation in which embedded.

Aldred's System.—Figs. 26 and 27, Plate 17, show the construc introduced by Mr. Aldred. The rail is made in two pieces, not riv together, but of such a form that, when keyed in the chairs A, may be said to be dovetailed together, the combination formi reversible or double-headed rail. These rails require no punc or drilling of holes for fishing; their peculiar shape enables the be dropped into their place within the jaws of the chair, and o wooden key B being driven securely home they are firmly hel position. The rail is laid on timber cross sleepers, and is so far to the objection of being laid on a perishable material; there is no base-plate to support the adjacent paving stones. At each the paving stone on either side of the rail has to be cut or dre the objection to which has been previously pointed out. Wh the advantage of a double-headed rail is sufficient to compensat the extra weight of metal to be laid down in the first instanc moot point. For railways, at all events, the double-headed r not looked upon so favourably now as it was some years ago.

Winby's System.—Figs. 28 and 29, Plate 18, represent Mr. Wi

system. It is somewhat similar to Mr. Gowan's, but some of the difficulties of making are successfully grappled with; the base or foot is not so wide, the rail being mounted on a base-plate. This system has also been used without a wide base-plate, the rail being laid on cross sleepers and spiked down with dog spikes, like an ordinary contractor's road. The inner edge of the rail A, Fig. 29, is rolled flat in the bar, as shown dotted, and is afterwards turned up while hot, as shown full. This saves planing out the groove, but it may be a question whether it does not tend to weaken the rail in what is already a weak part. It is a common cause of failure for a rail to split along the bottom of the groove, and this tendency is augmented by the action of the tramcar wheel.

The flange of a tramcar wheel, having to travel continually round sharp curves, becomes worn, by friction against the sides of the groove in the rail, to the shape shown in Fig. 30; while the tread of the wheel and the top of the rail are also worn down, till the flange bears on the bottom of the groove. The flange then acts in a similar manner to a revolving cutter in a tube-cutting wrench, especially with chilled wheels. The author has taken up many rails split along in this manner. To delay the operation of this cause, the brake-blocks on tramcars are now made of iron, and so arranged as to bear on the flanges as well as on the treads of the wheels, and thus to wear the flanges down also; but if once the top of the rail is worn down in any part sufficiently to allow the flange to bottom the groove, a very short time suffices to destroy the rail in the manner indicated.

Mackisson's System.—Figs. 31 and 32, Plate 18, show one form of Mr. Mackisson's construction. This consists of a cast-iron longitudinal sleeper, with broad base-plate, the principal novelty being in the method of securing the rail to the sleeper. It will be seen that the rail has a central web of a dovetail shape, which is secured in a groove cast in the sleeper, by means of keys driven at intervals along its length. Mr. Mackisson describes several other sections, and methods of fastening them to the sleeper, but the general construction is the same. In Figs. 31 and 32 the keys A are dropped into the groove in the cast-iron sleeper, through slots B

cut in the bottom of the groove in the rail, and are then driven with a drift. The long slot necessary to drop the key through in the author's opinion, weaken the rail in what is already weakest part. Figs. 33 and 34, Plate 18, are different sectio reversible rails, so arranged that the surfaces in and out of us at right angles to each other or nearly so. The manufactu such sections seems likely to present much difficulty; and with re to the sleepers there is the objection before alluded to, namely being in cast iron they are necessarily in short lengths.

General Conclusions.—The author has now briefly noticed the l methods of tramway construction, having for their object the rem of various defects indicated by experience, and also designed to the requirements of steam traction. There are many other sys which are better known than those selected, but they do not so meet these latter requirements, and therefore need not be d upon. None of the methods described in this paper have been enough in use as yet to enable a complete comparison to be ma their merits. They all possess good qualities in different directi and no doubt will in each case be found to remedy some of defects with which experience has made us acquainted.

The author has throughout referred to steam alone as a m power for tramways; and for the reason that according to our pre knowledge it is the only available power. Compressed air ans admirably in every way except one, but that one most effectu shuts it out from all competition with steam. Where compre air is used as a motive power, principally in underground operati it has been found by experiment that the resultant efficiency o working engine, as compared with the air-compressing engine, ra exceeds 30 per cent. Consequently the difference in cost, under most favourable conditions, will be as 3 to 1 against compressed This difference is sufficient to justify us for the present in discar the idea of compressed air, as a motor for tramway purposes. same objections apply, though not perhaps to the same extent the hot-water or fireless engine, invented by Dr. Lamm of Ame Several modifications of this type have been tried with vary

success. The chief reason that its use has not been extended is doubtless the financial difficulty; and even with steam traction, it must first be satisfactorily demonstrated that it is cheaper than horse-power, and it will then become practically universal.

At no very distant date, in the author's opinion, horse tramways will be the exception and steam tramways the rule; and for this reason, amongst others, namely the superiority of steam as regards safety to the ordinary traffic. The author is aware that just the converse of this is now urged by many persons; but in this, as in everything else since the beginning of time, the majority of to-day becomes, by the spread of knowledge and the light of experience, the minority of to-morrow.

The following is the comparative net cost of the different systems described, each taken per mile run of single line. These figures are estimated for permanent-way materials only, and do not include cost of laying, or of paving, concrete, &c.:—

	£	
Ordinary line, timber longitudinal and cross sleepers .	1150	
Larsen's system, wrought-iron sleeper, and base-plate	1400	(1)
Barker's system, cast-iron sleeper, ...	1556	
Gowan's system, wrought-iron, ...	1760	
Aldred's system, chairs, and timber cross sleepers .	1100	(2)
Winby's system, wrought-iron, with base-plate . .	1550	(3)
Mackisson's system, cast-iron sleeper, with base-plate	1600	

With respect to the comparative cost of steam and horse-power, the first has not been in operation long enough to give reliable and accurate data respecting the cost of maintenance of tramway engines; and moreover this is an item which, with improved permanent way and engines carefully designed, will be

(1) 78¾ tons rails (50 lbs. per yard) at £7 = £549 10*s.*; 93 tons sleepers and base-plates at £7 10*s.* = £712 10*s.*; small materials, &c., £138; total £1400.

(2) 94 tons rails (60 lbs. per yard) at £7 = £658; 30 tons chairs at £5 10*s.* = £165; 1760 sleepers at 2*s.* 6*d.* = £220; keys, spikes, &c., £57; total £1100.

(3) 121 tons rails (77 lbs. per yard) at £9 15*s.* = £1179 15*s.*; 47 tons base-plates at £7 = £329; small materials, &c., £41 5*s.*; total £1550.

continually decreasing. The author believes that, if the roads been better in the first instance, steam traction would have more prominently to the fore than it has as yet; but so many m ability and experience are now devoting their energies to the sol of the problem of applying mechanical power to tramways, tha ultimate success is assured.

According to Mr. D. K. Clark (Railway Machinery, 1855) resistance to traction on a railway may be as low as 6 lbs. per If this is the case, the haulage of tramcars over grooved rails never be accomplished at so cheap a rate as those prevailin railways. In 1870 the author made a series of experiments on New Cross tramways, using a dynamometer to register the resist to traction; and on a level and straight road in good condition, under favourable circumstances, the resistance was as much 18·2 lbs. per ton, or about three times the force necessary railway under similarly favourable conditions.

This great difference in the traction on a tramway, as comp with a railway, may be in some measure due to the build of the inasmuch as they have a very short wheel-base, and consider overhanging weight at either end. Engines for tramways, especi the earlier ones, have also been made usually with a short wh base; but latterly they have been fitted with a pair of small lea wheels, and with very good results. Doubtless some modificatio this direction will take place in the wheel-base of the cars, a lower resistance to traction will probably then be observed.

The author has thus brought finally into view what, among defects and objections admitted or supposed to exist in tramway the greatest of all, namely, the necessity of having a grooved level with the surface of the road. The exigencies of the high however render this condition an absolute necessity; and all energies must be devoted to minimising the inconveniences whi inevitably entails.

Discussion.

Mr. J. G. Lynde said there was one point in this very exhaustive paper to which he should like to direct attention, namely the estimates of cost. From the figures given at the commencement, it would appear that the cost of tramways, when they were first started, was something like £7000 to £10,000 per mile; but the estimates at the end of the paper varied, at present prices, from £1100 to £1760 per mile. Those last estimates did not of course include the paving &c., while the first estimates did. But, as far as he knew, the cost of paving with granite was about £2000 per mile; and when that was added to the latter estimates, it would still be found that the tramways cost originally something like double what they did now. Formerly, no doubt, a great deal of money was spent in the promotion of companies, which was not the case at present.

He quite agreed with Mr. Larsen that tramways should be laid, not on the elastic principle, like railways, but on the rigid principle, as in the systems which were now being adopted. Continuous iron bearings, whether of wrought or of cast iron, should be adopted throughout, and no perishable material should be laid beneath the surface of the ground. But one point, not touched upon in the paper, was the tendency to torsion in the rail when a great weight came upon it on one side of the centre line, as was the case when an engine was used on tramways. Therefore it was necessary that some support should be placed directly under the part of the rail upon which the weight was thrown. That was one of the reasons why he had himself adopted Barker's system, of which he had laid many miles in Manchester and its suburbs, Leeds, Derby, Edinburgh, Wallasey, Patricroft, and other places. In that system, Fig. 23, Plate 17, there was a cast-iron wall under the table of the rail; and this carried the weight fairly down to the bottom flange, and so on to the foundation; thus there was no tendency to torsion, and no vibration when the weight came on, such as occurred with rails having a web in the middle. Again, with the middle web

the top of the rail, being only 3 in. or 3¼ in. in width, had overhang of something less than 1½ in. on each side, to be filled un with concrete. But a wall of concrete 1½ in. thick was not wo much, and the vibration of the centre web against it would prevent ever forming a strong support for the rail, which was very essen if steam was to be used on tramways.

A base-plate beneath the paving stones he thought essential, in order to form a continuous bearing throughout for first course of paving stones alongside the rails. In one of busiest streets in Manchester the rails and paving stones had t been laid perfectly level at first, and they had never cost a penny repairs: they had been down three years, and were as good now when they were first put down. This was at the foot of the appro to the Victoria Station, where there was an immense cross-traffic, only a single line of rails. He regarded that as a very import point, because the repairs of the paving constituted one of the g nuisances in connection with tramways. If stones could get a from their work, they would; but with Barker's system there was upright wall of iron for the paviors to pave up to, instead of lo concrete or whatever else might be used. With Gowan's syst which was now being tried in Manchester, they were putting in ta fill up the 1½ in. space on each side the web, as they could manage the concrete. That system had an advantage in being entire steel rail, but had the fault that the weight came entirely one side of the centre web.

There was another advantage in having a continuous cast- sleeper, as in Barker's system. The hollow centre of the sleeper filled with concrete, merely however to add weight, not streng but that weight absorbed the vibration, and the consequence was the trams ran very easily and smoothly on it. The short lengt the sleepers was objected to in the paper; but he himself foun an immense advantage, as the lines could thus be easily laid ro curves, while the steel rail formed a complete backbone to the sys It was keyed down well to the sleepers at intervals of 18 inc so that they formed one continuous piece with it. In makin connection two months ago, a portion of Barker's tramway

Deansgate, Manchester, had to be taken up; and it was so solid that the sleepers and the foundation, which was a thin bedding of concrete, came up in one mass.

In the estimate on page 201, nothing was said about steel rails in Barker's system, but these were put down in every case; and it was hardly fair to compare that system with Gowan's, in which wrought iron, not steel, was used. An estimate could hardly be regarded as affording a fair comparison, unless the same material were used in both cases. It was of great importance to look forwards to the future repairs of tramways, as even a steel rail would eventually wear and require renewal. If the weight of the rail bore only a small proportion to the total weight, then the expense of renewal was reduced to a minimum. This was the case in Barker's system; but in Gowan's and similar systems, whether wrought iron or steel were used, the whole of the material would necessarily become scrap when worn out, and thus entail a cost for repairs nearly equal to that of relaying the line.

He might mention that, in the tramways he had laid down, the grooves were 1 in. wide, and the tyres of the wheels were chilled cast-iron. The use of timber beneath the rails was quite out of date; and the simpler and fewer the parts in tramway permanent way the better. As to the bearing of the steel rails on the sleepers, the paper mentioned a layer of tarred felt as being inserted; but in Manchester they just took a tar brush and brushed over the groove in the sleeper before the rail was slipped into it, and they found that no other bedding was necessary. The holes for the bolts were squared, and were made slightly oblong to allow for expansion. The length of the sleepers was 2 ft. 11 in. instead of 3 ft., which gave an inch play for the rail at the ends. It was then very easy to key the rails to them.

In conclusion he would give the prices that were now being paid for Barker's system. The figures given in the paper were about correct, but they varied of course with the price of iron and steel. The prices at present were as follows :—

Cost of one mile of single line of Tramway.

	£
53 tons steel rails (34 lbs. per yard) at £11 10*s*., say	610
180 tons cast-iron sleepers (114 lbs. each) at £4	720
Wrought-iron keys	15
1760 lineal yards, laying line—including opening out and removing roadway, preparing concrete bed 1 inch thick, and filling underside of sleepers with concrete—at 3*s*. 6*d*.	308
Cost without paving	£1653
4400 square yards best Welsh granite paving, 6 inches deep, on 2-inch bed of gravel, racked with broken granite, and run with asphalte complete, at 10*s*. 3*d*.	2255
Total Cost, including paving	£3908

Mr. R. C. Rapier, referring to Mr. Lynde's remarks on the cost of tramways, would venture to suggest that the first cost of the permanent way for a tramway was an item of the least possible consequence. The *best* construction for a tramway was of great importance; but whether it cost £1000, £2000, or £3000 per mile was of no importance at all. Mr. Lynde had drawn a comparison between the cost of permanent way, given at the end of the paper, varying from £1100 to £1760 per mile, and the whole capital account, given at the beginning of the paper as being £10,000 per mile, ten years ago. But the capital of a tramway company included not only the cost of its permanent way and paving &c., but, what was much more important, the cost of the vehicles, the horses, the stables, the depôts, and, what must not be forgotten, the Parliamentary charges; so that if £10,000 per mile was the average capital expended for tramways, the cost of the permanent way was not more than one-fifth of the whole cost of the undertaking. He believed that some tramways in London cost as much as £17,000 per mile of road; but of course the great bulk of that £17,000 must be connected with items of expense other than the permanent way.

He would suggest for the consideration of engineers whether they were not altogether wrong in one or two points with reference to tramways. A great effort had been made for several years past to get

the rail as narrow as possible, the idea being that horses were apt to slip upon iron rails. It was a great pity that such a fallacy should have been so implicitly believed for so long a time; but it was incumbent on engineers to endeavour to get rid of such erroneous ideas. It was clear that a tramway in any town was made for the benefit of the inhabitants of that town; and the more the tramway could be used, the better for those inhabitants. If the tramway was only used as at present by about one vehicle out of thirty-five, while the road was made simply abominable for the other thirty-four vehicles, he maintained that that was not first-rate engineering. Why was the road thus spoilt for all other vehicles? Firstly, because the rail was so narrow; and secondly, because the inevitable joint between the stones and the rails, described in the paper, happened to be so near the gauge of the wheels of the other vehicles, that one wheel was always hugging the groove on the one side, while the other wheel rattled about somewhere near the joint between the paving stones and the rail on the other side. If any one would carefully examine the condition of the paving adjacent to the rails of the tramways in London, he would find that there was a subsidiary groove worn in the paving stones, alongside the rails, by the wheels of the ordinary traffic. The remedy for both these evils, in his opinion, would be to make the rails wider. He had himself laid down some rails of considerable width, as described in Proceedings Inst. C.E., vol. L., page 38. The principle he went upon was this: that, whatever the surface of the tramway was made of —whether of steel, wrought iron, or cast iron—the wearing surface ought to be wide enough to take the wheels of any vehicles that at all approached the gauge of the rail. The gauge of the rail was 4 ft. 8½ in., and the gauge of almost all other vehicles was comprised between 4 ft. 7 in. and 4 ft. 10 in.

Reference had been made to the fact that the success of steam traction had been very much delayed by the imperfection of the permanent way. He submitted that the permanent way should be improved by having more of it in quantity, but in fewer pieces. For that reason he approved of Gowan's system, because it was in one continuous girder; and although originally the grooves had to be planed out, he believed he was right in saying that that was no longer

necessary, and that the rails were now rolled with the groove
With reference to Mr. Lynde's objections to the 1½ in. wall of
on each side of the rail web, he did not apprehend that M
supposed his rails to get any very great support from the con
was simply necessary to fill in the space with some in
material, so as to make a fair joint with the paving stones.

He thoroughly agreed with what had been said in the p
it was useless to go on opposing tramways. He himself ha
and suffered from them greatly, especially on account of the r
and severe shaking in driving along a road laid with t
That state of things was discreditable, because engineers ou
something better. But as regarded the eventual success of t
and of steam power on tramways, he thought an engineer m
very little faith in his profession, if he had any doubt as to t

With respect to the cost of compressed air on tramways
he thought the author had overlooked the fact that a small
steam engine was not itself a very economical motor. It was
an open question whether the compressed-air system or the
system might not compare favourably with the steam-powe
inasmuch as their lower efficiency might be compensated by th
economy of the stationary boilers in use at the depôt. Wi
to the necessity or desirability of making the tramway
pieces, he might mention that the tramway which he h
referred to, as being made of wide plates upon concrete, was p
in one piece from end to end, *i.e.* for a length of 2¼ miles.

Mr. John Robinson pointed out that Mr. Rapier had
given no reason for his somewhat surprising statement t
was no difficulty in a horse passing over tramways without
provided the metal was not too narrow. As far as his own e
went, wherever there was a large surface of metal, esp
wet, or covered with grease or mud, there was the greatest
a horse of slipping upon it. With regard to what had been
reference to the improvement of tramways, he had been
with the experience which a few weeks' driving in Manch
lately given him; for at the present time he could not eve

where the tramway was, unless he saw it. He thought one of the greatest successes yet achieved in tramways was that in Manchester there was now a tramway which was almost imperceptible. That tramway was, he believed, on Barker's system.

Some time ago, when the Corporation of Manchester was proposing to lay down tramways in the streets, he was called upon by Mr. Lynde to give his opinion—not as having had experience in tramways, but as to the general construction of a road which should be most economical in the first instance, and (what, as Mr. Rapier had observed, was of far greater importance) should afterwards require the least amount of repair. Nevertheless he did not quite concur in Mr. Rapier's idea, that, because a rail could be got in one piece, therefore the facilities which Barker's composite system seemed to give should be thrown away. First of all, in Barker's system there was a very easy mode of paving up to the side of the tramway. It would be seen by Fig. 23, Plate 17, that the system consisted of a flat rail with a central rib, connected with a series of cast-iron sleepers, the whole presenting a very square side, up to which the paving stones could be brought quite close; and the result was that in Manchester the rail was, as he had said, almost imperceptible when driving over it. There was besides the great advantage that if the steel rail became cut and split, in the way described in the paper, by the action of the wheels, it was possible, by simply removing the adjacent blocks, to take away the rail and replace it with a new one. If, when a rail had to be changed, it was necessary to take up the whole road, disturbing the concrete and the pavement, that was a much more serious affair; and practically a road made in that way would be left to go very much longer after it needed repair than a road made on Barker's system, because of the greater ease with which the latter could be taken up and the rail changed. He was by no means disposed to say that in Barker's system they had arrived at something which was final, for he hoped they would still go on with improvements; but he thought for the present it met the general requirements of the public.

He was surprised to find from the paper how inadequate the Paris tramways had been to the requirements of steam traction. The tramways had been treated, as Frenchmen were liable to treat things,

by bringing them down to the very minimum of requireme
Nothing could be worse for a steam tramway than the shape of
rails which had been laid down in Paris. He therefore hoped
the difficulties which had been experienced in Paris by Mr. Ly
Holt, whom he was glad to see present, and by others, in regar
the use of tramway engines, would be very much lessened when
began to be used on such rails as had been laid down in Manche
They would then have a very good and substantial road, and t
would not be any necessity for doing what the author had descr
with approval, viz. adding a pair of small trailing or leading wh
on the engine. He thought any locomotive engineer would say
this would have a very bad result; not because it did not relieve
weight upon the other part of the engine, but because it adde
materially to the friction of the engine in working along the str
and passing round curves. On the contrary, a short wheel-base
needed; but it should always be remembered that the limit of
weight upon any pair of wheels was not determined by the engine,
by the carrying power of the road; therefore, if they had as go
road as that which he believed Barker's to be, they could prob
do without the third pair of wheels, working the traffic wi
four-wheeled engine, which facilitated getting round curves,
availing themselves of the whole weight of the engine to give adhe
for drawing the tramcar, which, with a greasy surface like
presented by street tramways, was a most important point.

He observed that the proportion of the frictional resistance
tramways to that on railways, according to page 202 of the pa
was very much what he had himself anticipated when discussing
question in Glasgow last year (Proceedings 1879, p. 402). Loo
at the very much higher amount of friction on tramways, he
sure that, whenever in country places it was possible to estab
railways with raised rails, instead of tramways, that course woul
permanently economical; but in towns it was of course necessar
have tramways.

Mr. Rapier explained that by a wide rail he meant a rail at
wide enough for a horse to plant the whole of his shoe upon. He

not alone in the opinion he had expressed about horses not slipping upon iron surfaces if sufficiently wide. He had lately had some conversation with Mr. George Hopkins, who had had very great experience in tramways, and he was very much mistaken if that gentleman was not of opinion that an iron surface was less slippery than granite.

Mr. A. Paget said it so happened that he had in his works a granite surface over which horses had to pass. The blocks were about 9 in. wide and 3 ft. long. On fine days he should say that a horse would stand as good a chance of keeping his footing on ice as on that granite. He also had some experience of iron plates about 9 in. wide; and he was sure that on a fine day, when the surface was bright with constant traffic, it was more slippery than ice. It was not the same when it was covered with mud, as it was then gritty, and there was not so much slipping. The iron was more slippery than the granite. The granite pitching in ordinary use was not a flat surface, but a number of narrow irregular edge surfaces with grooves between; and this did not cause horses to slip so much.

Mr. Rapier said that on the wide tramway he had alluded to, which had been in use for nine years, there was no instance on record of a horse ever having fallen. The traffic along it was continuous, and the horses sought the tramway of their own accord; in fact in one place a chain had to be put up to prevent their going upon it where they were not allowed. This was the Quayside tramway, Glasgow: the rails were of cast iron, 10 in. wide, with a central groove; and it was worked by horse traction, not by steam power. Figs. 35 and 36, Plate 18, were illustrations of the two forms in use: the broader one, Fig. 35, was on the public quays, and was chiefly used by ordinary vehicles without flanged wheels; whilst the narrower type, Fig. 36, was used when the tramway was intended for flanged wheels only. The cost of the broad tramway was about £500 per mile more than that of other tramways, but its cost for maintenance, during nine years of incessant traffic, had been *nil.* The cast-iron blocks were about 9 in. deep, hollow on the underside, and chilled on the top. They were cast in

lengths of 5 feet, and a few days before they were fixed they we filled with concrete; the ends of the castings also were not entire closed, so that when the blocks were fixed and cemented to th concrete bed, the concrete in adjacent blocks also became united, a this together with the bed really formed one continuous piece. Th was no difficulty from expansion and contraction: it would appe that the great extent of surface in contact with the earth passed the heat of the sun as rapidly as the exposed surface absorbed it.

Mr. T. R. CRAMPTON observed that the Institution had previou discussed the tramway question with regard to engines, and impression was now, as it was then, that the matter of the engine extremely simple; what was wanted was a solid road to put it on. If road was sufficiently solid to stand the wear and tear of the ordin street traffic running upon it, it would be strong enough for locomotive. To obtain that strength and solidity, the principal thi was a solid bottom, taking care to have the stone pitching set clos and solidly against the iron structure, and to keep all the strains i vertical direction, preventing all vibration along the lines of junct between the rails and the stones. Looking at Barker's system, Fig. Plate 17, from that point of view, it seemed to offer many advanta as compared with Mr. Larsen's system, Figs. 20 and 21. The action of the traffic, which was of a tremulous nature, must tend force apart all the connections in the latter system; and he sho imagine that it would soon disintegrate the inch or two of conc placed there. If something more elastic were put in, *e.g.* conc mixed with tar, possibly it might not disintegrate; but the would be much better without it. In Barker's tramway there simply a solid wall of iron, which could not get away from adjacent paving stones. The solid concrete filled in between the sides of the sleeper would become one mass with them, and w be as firm as if of one solid piece. Again, to get a strong the strains must be brought vertically on to the foundations; must be no side action producing a tremulous vibration in web, as there would be in the case of Larsen's system, Fig and 21.

Whether the road cost £1000 a mile or £2000 was not a very serious matter. There were so many other expenses connected with tramways that they could afford to spend almost any amount of money in getting a solid foundation. With regard to the estimates however, no information was given as to what was put underneath the base-plates. When a new road was to be made, was it intended to run steam rollers over the road and consolidate it, for two or three months, and then to put down some concrete and consolidate that? He mentioned this because in making the calculations everything ought to be taken into consideration; and in making comparisons the same elements and the same materials should be used. He believed that a great mistake had been made in using the 4 ft. 8½ in. gauge for tramways. A 3-ft. gauge was ample for all purposes. With that gauge everything was more simple, and it was possible to get round the curves more easily.

Mr. W. Lyster Holt had no doubt all were unanimous in believing that, sooner or later, steam, or some other mechanical power, would supersede horse traction. He had had great difficulties in Paris with regard to steam traction; but on looking at the rail that was there used (Fig. 11), and the sleeper, which was the same as in Fig. 2, it would be seen that it was practically the same as if a house wall were built without any footings, or as if the old bridge-rail had been laid with a sleeper of exactly the same width as the rail itself. No doubt the permanent way used in Paris would have been far stronger if the sleeper had been turned at right angles, with its width downwards, so as to give greater base, which was what was wanted, whether for horses or for steam.

In Paris it was found that the rail often sank, and the tyres of the engines, being wider than the rail itself, used consequently to ride upon the stones and wear away rapidly; and the jolting also seriously affected the valve-motion. Mr. Robinson had advocated a very narrow rail; but for steam traction, where all the force of the traction was transferred to the rails, there would then be a serious wear and tear of the tyre, which could be only 1 inch or 1¼ in. wide. For horse traction the narrow rail might do very well; but for steam

traction a wider rail was wanted, or else they would still have what had been the great difficulty with steam tramways—the engines being constantly in the shops for repairs.

He agreed that Barker's system was a very good one; but for himself he should prefer Gowan's, for the simple reason that this had in one piece what Barker's had in three pieces. Again, if Mr. Gowan's system was good, Mr. Winby's must be better, because he rolled his rail with the groove in, and so preserved the skin on it, besides effecting a saving in cost. The paper gave a comparison of the cost of various systems, but unfortunately in some cases no figures were given as to the weights; it was therefore impossible really to compare the costs of those systems with others.

Mr. Jeremiah Head observed there was one point which might be further discussed with advantage, namely the question of elasticity. In the early tramways timber sleepers had been almost universally adopted, because it was taken for granted that elasticity was necessary, and could only be secured in that way. But they were now coming to the point when engineers asserted either that sufficient elasticity could be gained with iron, or that elasticity was not wanted at all. Now, during the last two years, he had very frequently walked up and down a part of the North Eastern Railway, where the permanent way was laid upon wrought-iron sleepers—cross sleepers of inverted trough section, known as Mr. Charles Wood's system, and described by him to the Iron and Steel Institute (Journal 1878, p. 83). These iron sleepers had been laid down about two years ago, and had endured an extremely heavy mineral traffic. When they were first laid, and the ballast was fresh, he had observed a decided undulatory action across the sleeper as the wheels passed over it, as well as a torsional movement, giving evidence of considerable elasticity; in fact he thought quite as much as with the wooden sleepers that were laid on the adjoining lines. The ballast had now become packed pretty solid, and there was not so much of that motion to be seen; but the sleepers seemed to be standing well. There was no looseness about the fastenings, and no weak points that he could observe.

It seemed to him that elasticity was not so much a question of wood *versus* iron, as a question of form. With the deep girder type, as in Fig. 19, he should suppose the rail would be pretty rigid, because of the great depth; but much must depend on what the ballast was composed of below the bottom plate, and how it was packed, which, as Mr. Crampton had pointed out, was not shown. He was rather inclined to think that, whatever was done, there would be sufficient elasticity, even with wrought iron or steel girder rails, and that that elasticity would not of necessity tend to disintegrate the substratum. The conclusion he had come to certainly was that wooden sleepers might be advantageously abandoned, whether for railways or tramways, not only on account of the perishable nature of that material, especially when spikes were driven into it, but also because a far better construction could be made exclusively of iron.

Mr. F. C. Winby said that, when he had first turned his attention to the different sections of rails used on tramways, he had found it difficult to see the object of using a channel section such as Fig. 7, Plate 15; it could not be for the purpose of strength, because, though there was plenty of metal in the head for compression, there was next to nothing at the bottom for tension. But he soon saw that that rail had been designed, like many others, mainly to facilitate the rolling of the groove in the head of the rail. But a tramrail had to do a certain duty as a girder, to support a rolling load; and he had therefore sketched a rail after the section of a rolled girder, like Fig. 25 or 29, but he saw directly that he could not get it out of the rolls. Then it occurred to him that he might roll the lip A straight, and have it simply turned up in the last groove. He had a trial rolling, and it was successful the first time. There were other features however to be looked to. The ordinary street vehicles were driven over the tramrails on account of their smoothness; but not being of the same gauge, and having no flanges, the wheels of these vehicles ran on the stone setts which were laid next the rails, and forced them below the level of the heads of the rails. Then the wheels of ordinary vehicles, in crossing the tramway, were skidded against the rails; and it was this defect that made street tramways a nuisance. It was therefore

necessary to keep the rail and the adjacent stones strictly to the same level. His first design was to roll a broad bottom flange to the rail, as in Fig. 25, in order to give a bearing surface for the adjacent stone. Those however who were accustomed to rolling deep sections would know the difficulty of rolling a flange 7 or 8 inches wide, and also the difficulty of bending such a section to go round sharp curves. He accordingly preferred to use a longitudinal base-plate, which broke joint with the rail, and which would give a larger bearing surface than could be got with a rail alone. He had now laid about 30 miles of this line.

He could not see any advantage in Mr. Larsen's rail, Figs. 20 and 21, from its having the head separate from the web and foot, since a grooved rail could now be rolled solid; it was all very well to use a combination of the kind before that could be accomplished. The head could, of course, be easily changed; but the stones at each side would still have to be removed, and therefore there would be very little extra difficulty in moving the rail altogether, as in his own system. But the life of a rail was in fact so long that the extra amount of weight in the compound system would more than balance the saving in renewal.

He had had some experience of Barker's system. He had seen it laid in Manchester, where the Corporation had now arranged to lay his own line in preference to Mr. Barker's, simply because the latter had not the vertical strength required to distribute the weight longitudinally. In fact he very much questioned whether that rail would of itself carry more than 2 tons on 3-ft. bearings without serious deflection; whereas his own rail, as in Fig. 29, weighing 58 lbs. per yard, and 6 in. deep, had carried 20 tons without any perceptible deflection, and 30 tons without any permanent set, and with slight deflection. It was necessary to have a rail of something like that strength, in order to carry locomotives. Barker's system was really a series of cast-iron shoes, only 3 ft. in length, and simply fished by the rail; hence, like a chain, they would follow all the undulations of the road. With regard to the cast-iron bottom flanges, which were ½ inch thick, it might be true that they would suffice to carry a reasonable weight; but a ½-inch flange that could be broken with a

hand hammer would surely not do for Manchester traffic. Heavy loads coming across it, such as boilers or locomotives, would break off such a flange very easily.

It had been suggested that the width of the gauge should be less than that of ordinary vehicles. He was now laying down generally a 3-ft. gauge, which was quite sufficient, and gave room to put the wheels under the seats of the tramcar, while admitting of a good passage, nearly 3 ft. wide, along the middle of the car.

As to elasticity, this appeared to him to be unnecessary. Elasticity could only be for the purpose of smoothing down inequalities; but in a tramway it might be the means of bringing two inequalities together, and make matters worse. A tramway should have a good bearing surface on a strong base-plate, carefully and truly laid; then with wheels perfectly concentric and balanced, the tramcars would run perfectly smooth. He did not mean to suggest a road so unyielding and rigid as would break before it bent; but the idea of having an elastic rail, where there was a solid pavement, seemed to him to be very absurd.

Mr. Rapier had stated that he had laid a line which formed one solid piece $2\frac{1}{4}$ miles in length. In his own practice he generally reversed the rail, laid the base-plate upon it, riveted it up, and turned it over into its place; and he had turned over 200 yards at a time in that way. He thought that was very good work, and formed quite a sufficient length to have in one piece.

With regard to the flanges of the wheels wearing down to an acute angle, as represented in Fig. 30, according to his own experience the angle was much more obtuse than that shown. He had had cars running with a flange not more than $\frac{3}{16}$ inch deep, and they had taken the curves and ran round splendidly; there was not a single case of their running off. That showed clearly that there was no necessity to have such large grooves or such large flanges. He generally made the head of his rail about $2\frac{3}{4}$ in. in width. With so narrow a rail the wear and tear of the tyres, in locomotives, would certainly be very heavy; but it did not take up so much of the road, and was scarcely seen. In Nottingham, where he had laid 12 miles of line with this rail, he ventured to say that a stranger going there

would never know from simply driving over it that there was tramway there at all. It had been down two years; and on c curve of 35 ft. radius, where not fewer than 180,000 cars passed eve year, there was not the slightest perceptible wear. He had not u any concrete, but had simply consolidated the ground underneat owing to the rail having such a large bearing surface there was necessity for concrete in any case. The space under the rail-h was filled in with one part Portland cement to five parts sand; having had occasion to take up a piece of line that had been down t years, he had had great difficulty in getting the cement away fr the side of the rail. The strength of his system was so far beyo what it had to do, that there was no tremulous motion upon it.

Mr. R. Price Williams said it would be of great value if, from author's experience of eleven years, he could give the average ann cost of maintenance for some of the systems referred to. He been very much struck with what Mr. Lynde had said with reference the Barker rail at Manchester, namely that there had been practica no repairs at all for two or three years. Of course if that w generally the case, it would be a very important point in its fav The main part of the question, at least as set forth in the titl the paper—the endurance of the permanent way under st traction—had been scarcely referred to. From his experience railway permanent way, and looking dispassionately at this subj he thought a great many of the designs now shown would meet the same fate that many early forms of railway permanent way met with, *e.g.* on the Liverpool and Manchester line. Directly t designs—at all events those that were composed of so many part were subjected to the action of a locomotive, his notion was that would give way. With all deference to Mr. Robinson's preference the Barker system, he must say, judging from his own experi and looking forward to the necessary advent of steam locomo that the more simple form of rail, such as that of Gowan or Wi supplied those elements of permanency which he did not see in others. Engineers were now feeling their way with regard to permanent way of tramways, just as they did in the case of railw

Many members could remember, as he did, the time when Mr. Bridges Adams gave an exhaustive paper on the permanent way of railways (Proceedings Inst. C. E., vol. xvi. p. 226). A great variety of designs for permanent way were then discussed, all of which (Mr. Adams's included) had since disappeared.

He had recently been giving a good deal of attention to the subject of train-resistance, and he was certainly much surprised to find that Mr. Larsen's experiments with a dynamometer should give such a large amount of resistance as 18·2 lbs. per ton on a tramway. He dissented entirely from the reason stated for this in the paper (p. 202)—that it "may be in some measure due to the build of the cars, inasmuch as they have a very short wheel-base, and considerable overhanging weight at either end." On the contrary, Mr. Fisher, the chief engineer of the Taff Vale Railway, had always maintained, and it appeared to him with much reason, that the very short wheel-base used on that line was the very cause why the train-resistance was so small: therefore he thought some other reason than that assigned in the paper must be found. It should not be forgotten that in the groove of a tramway there was a *dirt* resistance, which might in a great measure account for the higher friction; and he thought there ought to be a disposition to deepen the groove on that account.

He could not agree that with the advent of steam locomotion elasticity could be done away with. It was now found in the case of railways that, with a more perfect substructure, a very much more solid road could be laid than formerly; and that weight as weight in the rail itself had, as Sir John Hawkshaw had said, a decided value. He thought therefore that with road tramways engineers ought not to go to the other extreme of having too light a rail; nor could they do entirely without elasticity. It might very well be, as Mr. Head had maintained, that an iron sleeper supplied in itself sufficient elasticity; but elasticity as an element in a durable road could not in his opinion be done away with.

Mr. John Robinson would ask Mr. Larsen what was the section of the tramway rails which in his experiments of 1870 gave a resistance

of 18·2 lbs. per ton; because that was an important item in the question.

Mr. C. E. COWPER asked whether, with regard to the newer systems which the author had so well described, he could mention where they had been in use, and with what success. With regard to horses liking to trot on iron rails, if wide enough, even if that were true, it must be remembered that, on a road where a tramway was laid, the traffic was generally considerable, and horses could not always be on the iron, but only stepped on to it now and then, when crossing the tramway at various angles, in passing other vehicles. Hence it appeared to him that the effect was the same as when, in walking on a good pavement, a person suddenly stepped upon a piece of orange-peel or an ice-slide; he would then be much more liable to fall than if walking across a frozen pond. If the rail must be made wide enough for the horses' hoofs to be always fully upon it, as had been suggested by Mr. Rapier, he did not see how that could be accomplished unless the rail was the full width of the road.

Mr. W. SCHÖNHEYDER asked what was the actual practice in paving close up to the rail, as shown in Figs. 19 or 23; whether the paving setts were dressed to the exact depth necessary, so as to rest on the iron, or were packed up with concrete or cement underneath.

Mr. WINBY said in the 30 miles of tramway that he had laid on his system, he had always packed up the setts underneath with about ¾ in. of sand, which had been rammed down to about ½ in.

The PRESIDENT observed that good setts properly dressed were very accurate in point of depth; and of course they would be properly made to fit the height of the rail. He partly agreed with what Mr. Crampton had said in reference to the severe shocks that tramrails received from the ordinary road traffic. He did not think that the weight of a light locomotive running along the tramway would produce anything like the same stress upon the rail, as a heavy weight passing *across* it. In the latter case the whole weight came

suddenly upon one point, whereas with a tramway engine the weight would be more distributed, and there would be nothing like the same shock.

Reference had been made to the rails being wide or narrow. He himself complained of the *grooves* being so wide, which he thought was one of the greatest reproaches to the present tramways. Many of those who designed tramrails did not seem to care anything about the carriages and other vehicles that would pass over them, but only about the wheels of their own cars. If some of those wheel-flanges wore to such an extreme thinness as shown in Fig. 30, why could not very thin steel flanges be used to start with—say $\frac{1}{4}$ in. or $\frac{5}{16}$ in.—and new ones be put on when they were worn out? The rails could then have narrow grooves, and the ordinary wheels would not drop into them. He threw out that suggestion because some of the grooves now in use seemed exactly designed to tear the wheels off a carriage; and that was in fact a thing which constantly happened.

Mr. Lynde asked leave to mention that some very heavy loads had gone over Barker's rails in Manchester, but he was not aware of any of the flanges having ever been broken off.

Mr. Larsen said, in reply, that little fault had been found with the paper, in regard to the different modes of construction mentioned; but he wished to make an apology to several gentlemen who had desired to have their systems described. As the paper was limited in extent, he could only refer to those methods which he thought most to be recommended in point of construction and of first cost. He was sorry he had not been able to obtain sufficient information to lay before the meeting as to the places where the different systems were in use, and the length of time they had been down. In regard to Mr. Barker's system, on his last visit to Manchester he came to the conclusion that the tramways there were the best he had ever seen in any city (and he had been nearly all over Europe); but nevertheless the sleepers were of cast iron, and he thought, if the paving stones were rammed there as they were in London and in many other cities, the cast-iron sleepers would be smashed continually; whereas a rolled

plate would stand any blow. That was the only objection reality to Mr. Barker's system. The placing of the support direct under the load, as described by Mr. Lynde, was all in the rig direction; but he considered that the single-rail systems were equal strong, being on just the same principle as the ordinary Vigno rail.

The President and others had referred to the depth and width the groove. He might mention that the Board of Trade had n adopted a rule that no groove should be more than 1 in. wide a $1\frac{1}{8}$ in. deep. That might be admirable from the point of vi that a tramway should be so laid as not to be noticed; but he piti the horses that had to drag the cars along such a groove. M Robinson had asked what kind of rail was used in his experiments New Cross. It was the rail shown in Fig. 7, Plate 15; and the ca had American wheels, which had deep and broad flanges. No dou the fact of the wheels being new and the gauge tight had somethi to do with the high resistance; and also the fact that the ra deflected considerably. Since that time a great many improvemen had been made in wheels.

With regard to the question of first cost, it was all very well the case of such towns as Manchester or Liverpool to constru tramways in the very best way without reference to expense; b in outlying districts, and in lines worked by a company, the questi of economy in first cost was a very important one, because it w necessary to make the lines pay.

With reference to the use of steam, the section of rail in Fig. 17 w that on which most of the steam traffic in Paris had been carried; b as he had stated in the paper, he was limited as to weight with th rail; consequently it was made hollow underneath, and thereby stiffness was diminished. With reference to the observations Mr. Holt, he could only repeat that the lines on which steam h been tried had never been originally constructed for it.

With regard to the number of wheels for tramway engines, might point out that most of the engines now used had four drivi wheels and two uncoupled leading wheels; and that was a gr improvement, because the leading wheels took any blow that mig

be given by a joint, and bent the joint down so that the centre wheels followed easily over. They also prevented the great oscillation caused by the overhang, where so short a wheel-base was used as was generally the case in both tramway engines and cars: with both of which this oscillation was very serious, wherever a slight fault existed in the permanent way. Of course the two uncoupled wheels were capable of taking a radial position.

Mr. Crampton had enquired about the foundations usually employed below the sleeper. With the systems shown in Figs. 19, 20, and 21, Plate 16, he used 6 inches of concrete, and that was the usual depth. As to the setts, the arrangement simply was that, if the road was to have a 6-in. pavement, the girder was rolled accordingly to suit that depth.

He could not admit that Mr. Winby's rail was superior to that in Fig. 20. If the latter was worn out, and had to be renewed, all that was necessary would be to take out the bolts and replace the rail with a new one; whereas in Mr. Winby's or Mr. Gowan's rail, the whole would have to be cast away as scrap. Mr. Gowan's rail; Fig. 25, was 92 lbs. per yard; whereas the whole structure in Fig. 20 would be something like 72 lbs. per yard. That was a great consideration in the first cost, and also in regard to maintenance. Mr. Price Williams had asked a question as to cost of maintenance; so far however the maintenance of tramways had really not been gone into. The matter was a great deal mixed up with other expenses, and there was great difficulty in getting at the actual results.

The President proposed a vote of thanks to Mr. Larsen for his paper.

The vote of thanks was carried.

The Meeting was then adjourned till the following evening.

The Adjourned Meeting of the Institution was h
Institution of Civil Engineers, London, on Friday, 23rd A
at half-past seven o'clock, p.m.; EDWARD A. COWPER, Esq.
in the chair.

The following paper was read:—

REMARKS ON CHERNOFF'S PAPERS ON STEEL.

By Mr. WILLIAM ANDERSON, of Erith.

The Russian language is so little understood in other countries, that it is almost by accident that the labours of the many very able scientific men of Russia come to be known in Western Europe. Chernoff's investigations are an example of such obscurity, alike discouraging to their author and a loss to the scientific world.

In order that a true value may be set on Chernoff's labours, it is necessary to explain that he has been for some years assistant manager of the Abouchoff Steel Works near St. Petersburg; and that before he was raised to his present position, he was more particularly connected with the forge, the Bessemer process, and other operations of the great establishment he now so ably assists in directing. It is important to note that the Abouchoff Works stand supreme in the world as regards the variety of the processes there carried on. Under the able and energetic management of the Director, Captain Kolokoltzoff of the Imperial Navy, the Abouchoff Works have developed from comparatively small beginnings to their present magnitude; from an establishment in which puddled steel was melted in crucibles and cast into relatively small masses, to great works, making use of every modern method of steel manufacture.

In addition to the old casting house with nearly 2000 crucibles, the Siemens crucible furnace, the Bessemer converter, and lastly the Siemens-Martin open-hearth furnace and the Whitworth fluid-compressed steel process, are all to be seen in operation. The forge has a dead-weight 50-ton steam-hammer, a 15-ton hammer, and

a whole array of smaller hammers. There is a tyre mill, and th are extensive workshops for the manufacture of ordnance of eve calibre and of their projectiles, for the production of the heavi masses in steel, whether for commercial or war purposes, for t making of gun-carriages, for crucible manufacture &c. Lastly, order that the work may be carried on in a scientific manner and assured principles, the establishment is provided with an admira laboratory, with one of Kirkaldy's testing machines, and with eve appliance necessary for investigating the nature and properties of metal which forms the staple product of the place.

With the opportunities which the Abouchoff Works present, with the aid and encouragement of Captain Kolokoltzoff, second by his own remarkable talents and indefatigable industry, it is surprising that Chernoff should have produced a series of pap addressed to the Imperial Russian Technical Society, which h thrown a strong light upon the theoretical as well as upon practical aspects of the steel question.

Chernoff has another important claim to consideration, whic that he is perfectly unhampered by trade jealousies and trade secr So far from being able in any way to derive benefit from keeping own counsel, his reputation in his profession will be increased making his work as public as possible, and by drawing aside veil that some manufacturers have studiously wrapped about t processes.

Again, the manufacture of guns, especially breech-loading of heavy calibre, presents exceptional advantages for ascertai the internal structure of the steel produced. The bore of the is cut out of the solid by means of crown cutters, which gives opportunity of obtaining samples of the centres of the ingots. perforation of the slot through which the breech block works, ena samples to be obtained at every point in a radial direction; and surface tool work exposes the outer portions of the mass to observer. The strengthening rings and hollow projectiles, in manner, give great facilities for observing the structure assume the metal under various conditions both of form and dimensions.

Chernoff's first paper of note was read in 1868, but did not

under the writer's notice till 1876. He was then so struck by its merits that he translated it, and distributed the few copies that were printed, at first among his friends, and afterwards to many strangers interested in steel manufacture, who applied for copies as soon as the paper became widely known through notices in the professional journals. In this paper Chernoff first lays down the proposition that steel is a combination of pure iron and carbon; and that all other substances must be regarded as impurities more or less pernicious, although the introduction of an extraneous substance may, in some cases, actually have a beneficial effect by neutralising the injurious action of some other substance. He next broaches the theory that steel changes its properties as its temperature ranges from zero to its melting point: that up to some temperature *a* steel will not harden; that it may be further raised to a higher temperature *b* without undergoing any molecular change; that between temperature *b* and the melting point an amorphous structure is assumed; and that in cooling from the melting point to temperature *b* the metal will crystallise according to laws which are well known as governing the crystallisation of alum and of similar salts. The theory is supported by very clear reasoning and by the evidence of practice on a large scale, and seems to explain perfectly all the phenomena of annealing.

In 1876 a paper was read on "Materials for the study of the Bessemer process"* in which the Author's object is declared to be more to make the process understood and appreciated in Russia than to bring forward any facts previously unknown. He remarks that, after twenty years of successful working in Western Europe and the United States, only two sets of apparatus had been set up in Russia, and that of these two sets only one was in actual work; and attributes this backwardness to a want of knowledge of the principles and practice of the process. The paper gives a number of interesting analyses made at the Abouchoff Works and elsewhere, and institutes a comparison as to the dimensions of apparatus, quantity of air required, and other details, in different countries and for various qualities of iron.

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* Translated *in extenso* in the Metallurgical Review, New York, 1878, p. 457.

In 1878 appeared the paper on the Structure of Cast-S which the writer has translated, and which is now in of the Members (Proceedings 1880, p. 152). This paper the first instance on the defects met with in steel ca investigates their origin; next the means by which th obviated or corrected are discussed; and finally, the que whether steel castings need forging, or other modes of order to give them the tenacity which should be due to th composition of the steel from which they are made. experiments are cited to show that with proper an conformity with the principles laid down in 1868, cast st as tough, tenacious, and ductile as the forged metal.

One result of the investigation of the Research Co Steel has been to draw attention to the important occluded gases seem likely to play in any theory on the and tempering of steel. In treating of the analysis o escaping from the Bessemer converter, as given by Tamm, Chernoff remarks on the total absence of hydro the first three to five minutes of the process; and e circumstance by supposing that the hydrogen, which aris decomposition of the moisture of the air blown in, is at fir by the liquid iron; but that in the course of a few metal becomes saturated with the gas, and consequentl afterwards to escape. This is confirmed by a fact an Müller in a recent communication to the German Chemi namely, that his analysis of the gases occluded in cast- showed that from 68 per cent. to 90 per cent. was c hydrogen, the remaining gases being nitrogen and carb the latter in very small quantities. He estimates the pres occluded gases at 8 atmospheres; and this estimate singular confirmation from a process now being introduc United States and into this country, namely that of ca ingots to set under steam pressure directly applied. In a by Mr. Alfred Davis before the Iron and Steel Institu 1879, p. 476) this process is described, and the pressure stated to range from 5 to 10 atmospheres.

The astonishing rapidity with which hydrogen passes through red-hot steel, even against the pressure of the atmosphere, has been demonstrated by Regnault. He connected a steel tube to a hydrogen-generating apparatus at one end, and to a barometer tube at the other; and after keeping the steel tube at a red heat for from 8 to 10 hours, with a stream of hydrogen passing through all the time, he suddenly shut off the gas, when in about 18 minutes a vacuum of 29 inches was indicated by the barometer gauge, the vacuum rising at a uniform rate.

This power of diffusion seems to explain how under pressure, or other favourable mechanical conditions, the porosities in steel castings may be obliterated, without any obstacle being presented by the hydrogen or other gases imprisoned within them.

The experiments made by Edison on the evolution of occluded gases from platinum wire, with the consequent hardening of the metal, have led the writer to the theory that the hardening of steel may be due to the escape of hydrogen or other occluded gases during the heating of the steel: the sudden cooling in water or oil would then prevent their re-absorption, and so enable the particles of steel to approach more closely to each other, thus rendering the metal harder and more dense.

But, if this view be correct, the specific gravity of hardened steel should be greater than that of the same steel before hardening; whereas it is well known that steel "swells" and becomes more bulky when hardened, and its specific gravity decreases. Caron has given very precise information on this subject. The writer however considers that the observed reduction of specific gravity is only apparent, and not real; and is caused by the increase of volume due to the fact that the outer layers of the steel, which cool first, are unable to contract, and thus, becoming stretched beyond their elastic limit, receive a permanent elongation which the subsequent contraction of the inner portions is not competent to reduce.

According to this view the strains in a piece of steel, hardened all over, resemble those in a cast-steel ingot, as described by Chernoff. The outer layers are at first stretched, while the inner ones are compressed; but when the steel is quite cold, the outer layers are compressed and the inner ones stretched.

If however a piece of steel is hardened from one side only- example by cooling it on a slab of cold iron having a thin strea water running over it—the specific gravity will be found to l increased and not diminished: and moreover the bar will have bec concave on the hardened side, showing that it has there contra and has consequently become more dense. This experiment author has tried, and has thus been able to verify the statement Regnault, that the specific gravity of hardened steel, when particles are free from strain, is greater than that of the same before hardening.

But the main difficulty surrounding the hardening and tempe of steel, is to account for the gradual softening as the hardened is slowly heated again. This difficulty has been sufficient to u the theories of Jullien and others; but the writer thinks that new theory offers a ready explanation. As the hardened ste heated, the pores are opened; gas is again absorbed, and, the tempered steel is again quenched, retains the molecules at precise distance apart by which they were separated when quenching began.

The characteristic colours may also be explained by suppo that the opening of the pores of the metal causes changes the surface of the steel sufficient to account for the change of col The theory by which it is commonly sought to explain t colours is that a film of oxide, forming on the surface of the s plays the same part as the thin surface of a soap-bubble, or as films of tar or oil floating on water. But, in the first place, colours exhibited by steel are not iridescent, but each degree hardness is indicated by a uniform colour; and in the next place hues produced by thin films are only observed in transparent bod and are caused by the interference of rays of light, reflected pa from the upper and partly from the lower surface of the films. oxide of iron, however thin, is never known to be transpar Moreover, to produce a given tint, the thickness of the film mus some definite minimum quantity, or else an even multiple of quantity; but the colours characterising particular degrees hardness are constant, though produced under the most vary

conditions of time and hardening medium; and it is difficult to conceive that the films should in all these cases always assume one of the several definite thicknesses necessary to satisfy the theory. It therefore seems more probable that a change of surface takes place, and that the colours are due to diffraction rather than to interference. Mr. Hackney has suggested that the question might be settled by tempering in a reducing atmosphere, instead of in air; but such an experiment will not be conclusive, because the absence of the ordinary gases surrounding steel during the process of tempering may affect the surface of the metal.

A new and most sensitive instrument for ascertaining the molecular condition of metals has lately been placed in the hands of metallurgists in Professor D. E. Hughes' "Induction-currents Balance." A description of this instrument will be found in the Proceedings of the Royal Society for May 1879 (vol. xxix., p. 56). By its means it is possible to detect extremely minute changes of structure, and to compare unknown specimens with any desired standards. In investigations connected with the molecular conditions of steel and other metals, chemical analysis is of comparatively little value, and is at best difficult, tedious, and costly to perform; whereas Professor Hughes' instrument appears to give the means of detecting not only chemical but also structural changes of very small amounts.

The above remarks, which the writer has been led to make by way of comment upon Chernoff's paper on the structure of Cast-Steel Ingots, are intended to show the direction in which the enquiry into the Hardening, Tempering, and Annealing of Steel, promoted by the Institution, is tending. It is of the utmost importance to elicit the opinions and to take advantage of the experience possessed by many of the members; but the writer feels that much time and some expenditure of funds will be needed, before the changes undergone by steel in hardening and tempering are satisfactorily explained.

Discussion.

Mr. Anderson wished to say, as an addendum to the paper, more recent investigations on the subject seemed to throw additi light upon the enormous importance of occluded gases in alte the molecular structure of steel. Prof. Hughes had lately bro under the notice of the Society of Telegraph Engineers circumstance, that single steel wires plunged into dilute sulp acid became brittle, without apparently changing their hardness; that this brittleness disappeared on heating. The natural explana which occurred to himself was that, when the wire was placed in acid, the acid was decomposed; and the hydrogen found its way the metal, and separated the particles to such an extent that cohesive power was weakened; the wire thus becoming brittle wi becoming hard. As soon as it was heated and the gas driven the metal returned to its normal state. Mr. Chandler Robert chemist of the Mint, had also shown an exceedingly intere experiment with palladium, a metal which absorbed about 900 t its volume of hydrogen gas. Two palladium wires were placed tall vessel full of weak sulphuric acid, with a current of electr passing through them. Oxygen was developed on the one wire hydrogen on the other; and the wire to which the hydrogen adh became visibly lengthened as the hydrogen was developed alon surface. But as soon as the current was reversed, and oxygen devel on the same wire, it shortened again. This showed the powe hydrogen in separating the particles of the metal from one anoth

The President asked Mr. Anderson if he had tried any experim with brass wire exposed to the air for a long time. It was common belief that such wire became rotten, but could be parti restored by heat.

Mr. Anderson was aware of the fact, but had not made experiments with regard to it.

Mr. W. S. Hall presumed that the cause suggested on p. 230 of the paper for the colours seen in steel at various tempers would make that an analogous phenomenon to the iridescence of mother-of-pearl, which was known to be caused by minute lines on the surface, and might be communicated by pressure to such a substance as sealing-wax.

The President said he might mention another fact of the same kind, which perhaps was not commonly known, namely that many years ago, in the Bank of England, Mr. Barton had made some steel buttons, having extremely fine lines ruled on the surface with a diamond. This produced the most beautiful prismatic colours, quite as fine as those of mother-of-pearl, and capable of being transferred to sealing-wax in the same way. Another example was what were called "diffraction gratings," one of which he had in his possession; it was a piece of glass which had been ruled with very fine lines, about 6,000 to the inch, and it gave perfect prismatic colours.

Mr. Arthur Paget observed that the effect produced in the buttons and the glass would be iridescent, and varying according to the angle at which they were viewed, like the colours of mother-of-pearl; it was therefore entirely different from the colours of tempering.

Prof. D. E. Hughes, F.R.S., observed that, in his experiments on the absorption of hydrogen by steel wires, he had found that the wires became exceedingly brittle: and naturally enough he then thought that hydrogen might have something to do with the cause of tempering; but up to the present time he had not been able to discover that this connection actually existed. On the contrary, by electrical and chemical demonstration, he had come to the following conclusion:—that steel in its natural soft state was simply a mechanical mixture of iron and carbon—not a chemical compound, nor even an alloy, but simply iron *plus* graphite or carbon; but when this steel was heated, the iron absorbed the carbon, and formed, at different temperatures, different alloys. The higher the temperature, the greater the amount of carbon that was absorbed; and if the steel could be suddenly cooled, while in this alloyed state, then

the carbon would be imprisoned in the iron, and the cold metal would be a chemical alloy of carbon and iron, which was very different from the iron *plus* graphite of the ordinary soft steel.

This was easily demonstrated by the differences in the electromotive force. In the soft steel the graphite was so separated from the iron that there was not one molecule of iron actually touching a molecule of carbon; but when the metal, after being heated, was suddenly plunged into water, it retained the condition of the alloy formed at its higher temperature, and consequently the molecules of iron and carbon remained in direct contact. A simple experiment, which all could try, would demonstrate this. Take two rods of steel, exactly similar; soften one and temper the other. In order to have exactly similar surfaces, both must be brightened with sand-paper. If they were then put into a mixture of one part sulphuric acid to nine parts water, a violent local action took place in the tempered rod, and bubbles of hydrogen were given off; and the steel would be dissolved so rapidly that a bar $\frac{1}{8}$ in. thick would be eaten away in a day or so. But in the same time the rod that had been softened would hardly be touched at all; in fact, if it could be got perfectly soft, there would be no action whatever. What did this prove? It was known that chemically pure iron was not attacked in dilute sulphuric acid; but if in the same liquid metallic contact were made between the iron and some metal having a higher electro-negative force, a voltaic cell was thereby at once formed: the water was decomposed, the oxygen uniting with the iron, and the hydrogen being given off at the negative element. Now carbon and iron formed a most powerful voltaic cell; and if, instead of a separate piece of carbon being used, powdered carbon were brought into direct contact with the exposed surface of the iron, a series of separate cells was constituted, one at each contact point of the carbon; in other words, local action took place. In the case of tempered steel this local action was far more violent than if powdered carbon alone were used, since each molecule formed an independent local circuit; consequently rapid corrosion or solution of the iron took place. On the other hand, in the untempered steel there was no violent action, because the graphite was so separated from the iron molecules that they were not capable of forming a local circuit at all.

As already mentioned, there was no local action in chemically pure iron; but in ordinary commercial iron there was strong local action, due to mechanical mixtures of electro-negative impurities. In cast iron also there was still more powerful local action, due not only to the impurities of the metal, but also to the greater amount of carbon, which, having thus an increased pressure, was brought into more intimate contact with the molecules of iron. It was a wonderful fact that, in the case of good steel, such as the steel drilling rods used by watch-makers, the carbon should be so thoroughly separated, when the steel was softened, as not to be in sufficiently close contact with the iron molecules for forming local circuits. This was an experiment which everyone could make for himself; and he considered it most instructive as regarded the difference between tempered and softened steel.

There were also many other proofs. One was the great difference in the electro-negative force of iron in all the varieties from pure iron up to tempered steel. A chemically pure iron bar had an electro-negative force of a certain constant value. Hardened steel had a much higher electro-negative force; and the difference of that force from the former was a measure of the amount of carbon combined with the iron in the hardened steel. But softened steel had exactly the same electro-negative force as pure iron. Therefore the carbon in softened steel could not be in actual contact with the iron at all; and it was only when it took the form of alloy that it could be seized upon in that way and its quantity measured. These were some of the results of his experiments, and he mentioned them as an indication of his present views.

The President asked Professor Hughes if he had tried the difference in conducting power of hard and soft wires; because it would seem that particles which were separated from each other would not conduct so well as those which were in contact.

Prof. Hughes said experiments had been made by others on this subject (see Proceedings of the Chemical Society, Dec. 1879, p. 1000), from which it had been found that the conducting power of tempered

steel was much lower than that of soft steel. But this could
easily explained, because, although in soft steel the graphite
separated from the iron, yet the iron was in an amorphous st
while in the hard steel it was crystalline; and no crystalline substan
were good conductors.

Mr. JABEZ JAMES wished to give a little of his experience in
workshop with reference to the behaviour of steel. Some years
he had to make a cast-steel collar, 3 in. or 3½ in. diameter,
about 3¼ in. deep. He tried several ways of making it, and mad
many as nine before he succeeded. The collars seemed right eno
until he attempted to harden them, but then they cracked.
another case he had some cutters to make for the War Office, a
3 in. diameter and 1¼ in. thick, with a hole of about 1 in. diam
through them. In some instances they dropped in halves in
hardening, while in others they stood perfectly; they were all m
from the same bars, and the same workman cut the steel off
hardened it; the cutters were turned however by different work
He should be glad if any member could explain these peculiariti

It had often been stated that cast steel, unlike iron, could n
welded; but he had lately welded some large steel collars, 16 in. d
by 5 in. deep and ¾ in. thick, and in only one case had he faile
produce satisfactory work; and the welding of steel to iron c
also be done perfectly with proper care.

He might add that in the making of tools, a common chip
chisel for example, it should not be drawn by the hand hamm
the sledge hammer, but by the flatter. His reason for that opi
was that the marks of drawing were more frequent after the u
the hand hammer or sledge hammer than of the flatter; and
grain of the steel was no doubt more disturbed. With referen
turning tools, it was not the hardness that was most important,
the form of the tool, so as to give a correct cutting edge. The
would apply to drills and taps. He was quite convinced that i
unnecessary to have a tap very hard; its excellence depe
much more on the form of the cutting edge. If that was cor

there would be much less labour for the workman, and not so great a strain upon the steel.

Mr. W. Ford Smith observed that small pieces of cast tool-steel could be welded together, or welded to iron, without any difficulty, by the use of welding powders. He had used successfully one which consisted of ten parts borax and one sal ammoniac.

The President said common borax would answer the purpose perfectly.

Prof. Hughes asked leave to mention one other matter he had noticed in his investigations, concerning which he should like to know whether it was borne out by actual practice or not. When he heated a steel wire and softened it in the flame of spirit, as he generally did, then at the first instant after it had become cool the hardness was at its lowest point, but if the wire were laid aside in the open air, the hardness rose in value, and would do so to a considerable extent even in one hour. The experiments which had been carried out on crystallisation, as well as his own electrical experiments, indicated clearly to him that steel was softest at the moment after it had been softened: a day after it would not be so soft, and must therefore have crystallised partially when left to itself.

Mr. Arthur Paget believed there was some evidence that the converse was also true, viz. that steel, when too hard from some cause, became gradually softer. He had been told that, when Sheffield manufacturers found a parcel of steel too brittle, it was their custom to put it aside for some months, at the end of which time it would be much less brittle; but he had never made any experiments on the point.

At the request of the President he mentioned another matter which somewhat bore on the question, but he was afraid that he could not state it as a proved fact, although his workmen had a strong belief that it was quite true. He had for some years successfully used a system of hardening very thin steel plates without using any

water or oil, by pressing them suddenly while red-hot between two surface-plates, holding them there for a short time, and then when cooled dropping them out. If the thin steel plate was clumsily caught between the surface-plates, so that it was allowed to rest on the lower one for a very small fraction of a second before the upper one pressed it, it would come out considerably curved; and the men stated that if they attempted to straighten such a plate at once they could do so with the fingers, but that at the end of a very short time the slightest attempt at straightening would make it break in pieces. He was himself however in considerable doubt about the entire accuracy of that statement, and only mentioned it as, if true, possibly confirming to a certain extent Prof. Hughes's idea, that steel was softer at the first moment after cooling than afterwards.

Mr. W. W. Beaumont suggested that a study of the rationale of the method of production of Mushet's tool-steel might give some clue to the reason for the hardening of ordinary steel: that steel being very dense, and capable of turning cast-iron, wrought-iron, and some steels, without having undergone any hardening itself. He put it as a question, whether or not any inference as to the change undergone by ordinary steel in hardening was derivable from the explanation of the superior hardness of Mushet's unhardened steel, supposing that hardness to be produced by design from known effects of controllable causes.

Mr. John Robinson asked if Mr. Anderson could give any further evidence as to the statement on p. 228 of the paper, that, with proper annealing, cast steel was fully as tough, tenacious, and ductile as the forged metal. Upon that point he thought the meeting would b glad to have further information, because it was not according to the experience of engineers generally.

Mr. Jeremiah Head, referring to the question put by Mr. Robinson, wished to mention, what many present no doubt knew perfectly well, that formerly the ingots for making steel rails were

all hammered; but he believed that now there was hardly a steel rail mill at which the hammering of ingots was ever talked of. He had himself had some experience in rolling ingots into steel plates. When he began, he used to hammer the ingots after casting, under the idea that the plates would thus be more solid and of better quality; but finding that there was a great deal of extra waste due to the second heating thereby occasioned, he discontinued the hammering altogether; and the ingots were now simply cast flat, and then rolled without any hammering at all. The plates so made, as far as he had tried them, stood Lloyd's tests quite as well as if they had been hammered.

Mr. Robinson said his question related to steel castings in various forms, toothed wheels for instance, which could not be hammered or rolled. In Mr. Head's case the rolling of the steel ingot had to some extent the same effect in giving a grain to the steel as if it were hammered.

The President mentioned, with regard to the retaining of carbon in steel while annealing, that many years ago he had made a number of milling tools for use in the lathe, and had annealed them in oak sawdust; and he had found that by this means the steel was kept in good condition, instead of being impoverished by losing the carbon, as it would have been if cooled in the ordinary way. With regard to the sudden cracking of masses of steel when cooling, which Mr. James had touched upon, he might observe that sudden chilling in cold water had a bad effect upon many classes of steel. It was impossible for steel wire to be drawn hard, if it had been chilled in cold water; but if chilled in hot water it could be drawn without difficulty, while at the same time it was well hardened to about a full dark blue temper. That was particularly important in drawing steel for music wire, pit ropes, and steam-plough ropes. Steam ploughing in fact would not exist, if it were not for the hard steel-wire ropes. That wire had first been made in Austria, and was called Austrian music wire; but the process had since been introduced into this country, and had been in use for the last fifteen or twenty years.

Mr. JOHN FERNIE, referring to the splitting of large piec
such as cutters, said that the Americans, who used cutters
Englishmen, after they had rough-turned a cutter, and bo
softened it very much by annealing; and when finished
steeled it as it were, by putting it for some time in a
with charcoal or other materials. He believed Englishm
great deal to learn from Americans as to the treatment
Those who had visited the Exhibition at Philadelphia in 18
remember seeing a piece of American steel which had p
number of $\frac{7}{16}$ in. holes through iron 2 inches thic
steel was treated in some particular way; but he had
able to ascertain how. Most of the large cutters made in
were made, he believed, from Sheffield steel, but trea
particular way. With regard to the difficulty of hardenin
watch manufacturer in Geneva had told him that a great ma
from Sheffield came to him soliciting orders for steel, but
was only one firm on whom he could thoroughly depend to
steel that would not fly to pieces in hardening. In such t
workmanship expended upon the steel was many times th
the steel itself; therefore it was most important to get a per

Mr. JABEZ JAMES, referring to Mr. Fernie's remark
American plan of annealing cutters, asked leave to men
often, when steel came from the forge, and a rough cut
from it in the lathe, it was found to be very pinny. He h
cases where it would turn the edge of the tool or drive the
away from it. If steel of that class, after a rough cut
taken from it, was annealed in lime and sawdust, or lime and
it would be found to work very soft; but on hardening
again, unless it were again put through a process of charcoa
not take temper so well as it would before. With regard
they were very extensively used in this country, and he b
the cutters used in America were copied from English man

Mr. ANDERSON said, in reply, that the enormous difficul
subject had grown upon him the more he had turned his at

it. Not only was it extremely difficult in itself, but it required a great range of knowledge in physical science to be able to grapple with it: as had been forcibly brought out by what Professor Hughes had elicited by means of electricity, showing that it was necessary to take up that study also, in order to work out the question of hardening and tempering. Professor Hughes's reasoning from electrical facts went to show that there was a separation of the carbon in the form of graphite when the steel was soft, and a combination with the iron when it was hard. The difficulty he found in acquiescing in that statement was, that it had generally been supposed that the separation of carbon in the form of graphite must be accompanied by a weakening of the material. The reason why cast iron was so much weaker than steel was supposed to be that the excess of carbon in cast iron assumed the form of graphite in separate particles, and those particles were interposed between the particles of iron, and so reduced their cohesion. But soft steel was generally more ductile, and carried nearly as high a tensile strain as hardened steel; whereas it appeared to him that, if Professor Hughes's view was right, the quantity of graphite in the soft steel, which must be considerable, ought to weaken it very much more than it did.

It was desirable that the word steel should be better defined. He had written recently to his friend Mr. Chernoff, at the request of the Secretary of the Inst. C.E., with respect to the behaviour of steel under extreme cold, a paper having lately been read at that Institution upon the subject. In answer, Mr. Chernoff asked what they were talking about when they talked of steel. If they talked of steel in his sense of the term—*i.e.* a mixture or combination of pure iron and pure carbon—then his answer was that cold produced no effect whatever upon it. In the case of pure steel manufactured at the Abouchoff Steel Works, they were as willing to submit their tyres and other steel articles to any tests in the severest cold, as they were in warm weather. But if they talked of steel containing phosphorus besides carbon and iron, that was a totally different matter; and extreme cold produced a very sensible effect. Steel with phosphorus in it would stand a test in warm weather which it would not stand in cold. That fact seemed to confirm the previous

remarks of Mr. Chernoff, as to the extreme importance, w comparing the behaviour of steel under various circumstance being quite sure about the substance of which they were talk Carbon and iron was one class of steel; carbon, phosphorus, and another; carbon, phosphorus, manganese, and iron another; and car silicon, manganese, and iron still another. It was no more fai compare together steels containing different ingredients, than it w be to compare the behaviour of cast and wrought iron. No d it was the neglect of this important fact that accounted for a g many anomalies which were to be found in statements about behaviour of steel.

With respect to the hardening of steel, one of the ideas which been broached was, that it was connected in some way with greater or less proportion of hydrogen, or other gases, containe the steel; and that the hardening was caused by the particles of being allowed to approach more closely to each other, by reaso the gases being driven out from between them. If so, it would see follow that hardened steel ought to be of greater specific gravity unhardened steel. But it was a notorious fact that hardened "swelled," or became more bulky. Nevertheless he believe hardened steel could be got in a state of repose, it would be of gr specific gravity than soft steel; the difficulty was to get it in state. With a view of finding out what the condition of hard really was, he paid a visit to the Mint, and asked to see the which were used in coinage, and which were said to crack very c Sometimes they were finished and put away, and when afterw taken out for use were found to be cracked. He argued that if "swelling" of the steel was caused by the decrease of its sp gravity, there ought to be no particular strains to cause the crac It would be otherwise if the "swelling" was due to the une setting of the steel, the outer part first of all setting hard, and inner part afterwards cooling and trying to drag the outer part af in its contraction. In that case the inner part would be in a sta tension, and the outer part in a state of compression; and the ought to crack, not radially, but in circular cracks inside the layers. On examining a number of dies he found this to be act

the case. Two dies, with circular cracks of this kind, had been presented by the Mint to the Institution. Another die was cracked in the form of a narrow ellipse, which however showed the same tendency. Further he argued that, if a flat piece of hardened steel was cooled on one side only, it ought to be hollow on that side from the contraction of the steel at that part; and, as stated in the paper, he found on trial that this was really the case.

Mr. Robinson remarked that the elliptical form of crack at the centre of the bar was a common failure in ordinary bars of steel, as delivered from the steel manufactory without being hardened.

Mr. Anderson said it was at any rate clear that, if the crack was due to the outside being in tension, it would be radial. But the circular form was invariably the way in which dies cracked; and it showed what care there ought to be in such investigations not to jump hastily to conclusions. Taking the specific gravity of a piece of hardened steel in the ordinary way, and comparing it with that of the same piece when soft, it would be found that it was slightly less; whereas in reality, as he believed, the specific gravity of the hardened steel was greater, because the particles approached more nearly together than before.

With reference to Mr. Robinson's question as to the relative strength of cast and forged steel, he could only refer him to the translation of Mr. Chernoff's paper (Proceedings 1880, p. 182), where he would find the Tables alluded to. Several facts given in the previous pages confirmed the view that, when properly annealed, steel castings, as produced at the Abouchoff or Terre-Noire Works, were as strong as steel forgings. His own experience—and some years back he had used cast steel in very large masses—did not at all confirm that view. His own impression had been that the steel castings he had used were not many degrees removed from cast iron: but that was some years ago, and every year enormous advances were made in the casting of steel, so that he had no doubt the statements of Mr. Chernoff were perfectly correct.

There was a casual allusion in Mr. Chernoff's paper (Proceed p. 170) to the use of steam pressure in casting steel ingots. understood that the Terre-Noire Works, alluded to as having that system of casting, had not only tried but were actually it. In his own paper, it would rather appear as if he had assi the credit of using steam pressure in casting ingots entirely t Americans; but it appeared that it had been worked out independ by the highly-intelligent gentlemen connected with the Terre-Works.

In conclusion he would only ask all who had opportuniti doing so to communicate to the Institution every fact of interest came before them in relation to this very difficult subject. It quite impossible to tell what importance the facts might when collated with the other facts which the Research Comm was collecting, in solving the mystery which attached to the su before them.

The PRESIDENT asked the members to pass a vote of thank Mr. Anderson for his interesting paper.

The vote of thanks was passed.

The following paper was then read:—

ON WATER-PRESSURE ENGINES FOR MINING PURPOSES.

By Mr. HENRY DAVEY, of Leeds.

In this paper the author proposes to discuss some of the leading questions involved in the proper construction of Hydraulic Engines, such as are suited to considerable pressures; excluding from consideration turbines and similar machines, which cannot be correctly designated water-pressure engines.

Water-Pressure Engines are usually intermittent in action; nor is the author acquainted with any practically successful engine which works with a continuous and uniform flow. Rotary water-pressure engines have been employed and experimented upon, but, as far as the author is aware, without much success. Sir William Armstrong experimented with a rotary engine before he perfected his water-pressure machinery, now so well known (*see* Proceedings Inst. C. E., vol. L., p. 64).

Water supply, depending as it does on rainfall, is necessarily variable where there is not an impounding reservoir of sufficient capacity to compensate for the variations in the fall; and the great difficulty of forming such reservoirs, in localities where water power is available, is the chief reason why the mechanical energy of the water, which falls on the high ground and gravitates to the valleys, is not utilised more than it actually is. The subject however has not received the attention it deserves; and steam is often employed, especially in hilly districts, where water power would have been practicable and very much less expensive. Metalliferous mines are usually situated in hilly districts, and are often worked to the depth of the adjoining valley through an adit level. Several mines may be drained through the same level: a notable instance being the Sutro

Tunnel. In such cases water may be collected on the hill, and conducted through a shaft to an adit level, and there employed to work the mine; a practical example of this is given in a subsequent part of this paper.

The average yearly rainfall in England is 42 inches; but in hilly districts it is more, and probably averages 53 inches. The loss from absorption and evaporation must necessarily vary greatly in different localities; and probably not more than an average of 30 inches could be gathered into reservoirs, which is equal to about 1¼ gallon per minute per acre, or 800 gallons per square mile; or, in round numbers, one square mile of elevated ground contributes 24 H.P. for each 100 feet of elevation.

When the difficulties are considered of collecting and storing such a variable quantity as the rainfall (which varies in England between 20 and 70 inches per annum), it is easily seen that it is only in exceptional cases that the rainfall from elevated lands can be made available for power, unless where the natural contour of the hills contributes very largely to the desired result.

A body of water at rest in a pipe exerts at any point a pressure proportional to the head or vertical height of the column above that point. Let

h = the head of water in feet above any point,

p = the pressure in lbs. per sq. in. at that point;

then $p = 0 \cdot 43\ h$.

A column of water in motion in a pipe has an acquired energy expressed in foot-lbs. by

$$\frac{Wv^2}{2g} = \frac{Wv^2}{64 \cdot 4}$$

in which W is the weight in lbs., and v the velocity in feet per second. The acquired energy thus varies directly as the weight and as the square of the velocity.

If the velocity of a given weight of water is not altered, its acquired energy is not increased or diminished. But a column of water moving with an accelerating velocity exerts a less pressure than the same column at rest; and a column of water whose velocity is being retarded exerts a greater pressure than the same column at rest.

If a column of water in motion be suddenly stopped, its acquired energy is spent in producing a blow or shock; hence any water-pressure engine, in which the motion of the driving column is suddenly arrested n times per minute, loses in ft.-lbs. per minute the energy represented by $n\ \frac{Wv^2}{64{\cdot}4}$.

If a water-pressure engine be employed to overcome a constant resistance, its minimum power must be equal to that resistance; and if the velocity of the driving column varies, then its energy varies, and the energy due to the difference between the maximum and minimum velocity is lost.

Let v and V be the lower and the higher velocity alternately assumed by the water column, n the number of changes per minute, and l the loss of energy; then

$$l = n\ \frac{WV^2}{64{\cdot}4} - n\ \frac{Wv^2}{64{\cdot}4}.$$

Water-pressure engines are employed in pumping water, in winding materials from mines, and in driving machinery of various kinds.

For pumping water, the engine is usually applied direct to the pump, and in its simplest form is illustrated in Fig. 1, Plate 19, which represents the water-pressure engine erected by Trevithick at the Druid Copper Mines, Illogan, near Redruth. The engine consisted of a 10-in. double-acting hydraulic cylinder A, provided with a piston having a stroke of 9 ft. From the cross-head of the engine, spear-rods descended to work the pumps. The valves consisted of two lead "plugs," or pistons, B and C. Rods attached to these plugs passed through stuffing-boxes in the valve-chest cover, and were connected by means of a chain passing over a chain-wheel D. A lever on the axis of the chain-wheel was connected to the tumbling weight W. The movement of the main piston towards the end of its stroke, acting by tappets fixed on the piston-rod, caused the tumbling weight to be pushed over the centre, as in Fig. 2; and in that way the valves or plugs B and C were reversed, and the return stroke of the engine was effected.

If the plugs B and C were made to cover the ports, and thereb
to prevent all slip of water past them, then the driving colum
would be absolutely stopped at the end of each stroke, as wou
be also the delivery column of the pumps. The conseque
loss of energy would be very great, and would be determined
the expression given above. Severe shocks would also be produc
at the end of each stroke. To reduce the severity of these shoc
Trevithick made the plugs B and C less deep than the width of
ports, as seen in Fig 1, and thereby allowed water to pass throu
from the driving column to the exhaust during the reversal
the stroke, thus preventing the absolute stoppage of the driv
column. This device reduced the shock at the expense of wat
and the efficiency of the engine must have been small.

The loss of energy arising from fluctuations of velocity in
driving column is directly proportional to the weight of the drivi
column, and therefore to its length; consequently, when the heig
of the column is inconsiderable compared with its length, a
therefore its power small compared with its weight, the percent
of loss is very greatly increased.

In applying hydraulic power for draining the dip and dist
workings in mines, the author has practically experienced
difficulty of having to deal with a column very long compared w
its height. A practical example is given in Figs. 6 and 7, Plate
which represent two engines at Griff Colliery, near Nuneaton: th
are now employed to pump out a very long dip working, and will
kept for draining it permanently. There are two hydraulic engi
A and B, each capable of raising 150 gallons per minute to 150
height, through 800 ft. of 7½-in. delivery pipe CC, under an effect
head in the driving column of 450 ft., this head being supplied throu
1900 ft. of 5-in. supply pipe DD. In commencing to get out the wa
from the dip, the first engine was placed as near as possible to
surface of the water. Suction pipes E were then added, as the wa
was lowered, until a vertical depth of 25 ft. was reached; the seco
engine was then placed close down to the water-level, and the operati
continued. In that way the pumping was uninterrupted, and

distance of 150 ft. down the dip could be reached before it became necessary to move either engine, the inclination of the dip being 1 in 6. The water delivered at the top of the dip working is conducted to the sump S of the main pumping engines, and the water for driving the hydraulic engines is conveyed down the shaft from the surface of the mine; so that the main pumping engines have to pump the water delivered at the sump, which includes the water used in working the hydraulic engines. The exhaust water from the power cylinder is delivered direct into the rising main of the hydraulic pump, so that the hydraulic engines work with an effective head equal to the height of the supply cistern above the main engine sump S.

A longitudinal section of the hydraulic engines is given in Fig. 8, Plate 21. The stroke is 2 ft. 6 in., diam. of power cylinder 6¼ in., of pump 8¾ in. Thus the useful effect is represented by $\left(\frac{8 \cdot 75}{6 \cdot 25}\right)^2 \times \frac{150}{450} = 65$ per cent. The speed of working is 12 double strokes per minute. It will be seen that the pump is provided with a loose liner M; by withdrawing this liner, and putting in a larger piston of 12½ in. diam., the capacity of the pump is doubled, enabling the engine to pump double the quantity to half the height. The larger piston is used until half the total depth is reached, when it becomes necessary to insert the liner, and use the smaller piston for the remaining depth.

The valves of the power cylinder are of a very peculiar construction, and were designed by the author with a view to get rid of the difficulties encountered in applying slides, and other ordinary valves, to water-pressure engines. They are shown to a larger scale in Figs. 9 and 10, Plate 21. Referring to Fig. 10, the top orifice F is the inlet, and the bottom one G the outlet or eduction pipe; and the pipes J and K form communications to the two ends of the power cylinder. The eduction valves are annular gun-metal pistons HH, working vertically, and each having two valve-beats, one on the inner edge I and one on the outer edge O of its bottom face. As the annular valve descends, the outside beat closes the communication to the eduction pipe; and the inlet valve L, rising

against the inner beat, closes the supply. This inlet valve i ordinary single-beat mushroom valve, with its stalk proje upwards and attached at the top to a piston N; the bottom fa this piston is constantly under the pressure of the driving col while the top face is exposed alternately to the pressure of driving column and to the pressure in the eduction pipe, by m of a small gun-metal slide-valve P, Fig. 9, actuated by a lever Q tappet-rod R, Fig. 8. The action of the two valves in combin will be readily seen by supposing that the exhaust valve is cl and the pressure valve is open, as on the left-hand side of Fig then the pressure valve L, in closing, rises up against the an exhaust valve H, and lifts it, opening the exhaust orifice G. valves are now in the position shown on the right-hand sid Fig. 10. Towards the end of the stroke, an arm S attached t cross-head of the engine strikes the tappet and so pushes the s valve over, into such a position that the top of the right-hand v piston is exposed to the pressure column and that of the other t eduction column. The main valves are thereby reversed: the r hand piston being under equal pressure top and bottom, the pre on the top of the annular valve H forces it downwards, carrying pressure valve L with it. When the valve H has come down o beat O, closing the exhaust orifice, the valve L continues to des under the pressure above it, and opens the pipe K to the pre water, as on the left-hand side of Fig. 10. On the other sid ascending piston causes its inlet valve to close, and its edu valve to open. With this successive and alternate action of the v they cannot in working be placed in a position which would a any water to slip through uselessly; that is to say, it is impos for the exhaust valve and the pressure valve ever to be both of open at the same time. The opening of the exhaust valve depen the closing of the pressure valve, and the pressure valve cannot until after the exhaust valve has closed; so that it is impossibl either valve to be open except while the other valve is closed.

The practical effect of this action on the velocity of the dr column is to retard it, but not absolutely to stop it; and, i joint displacement of the two valve pistons were equal t

displacement of the main piston, the fluctuation in velocity, as represented in the diagram, Fig. 3, Plate 19, would be very similar to that caused by the working of two simple engines coupled by cranks at right angles to each other, which is shown in the diagram, Fig. 4. When the two hydraulic engines are in their final position, and can be placed side by side, they can be so arranged that engine A works the change valve of engine B, Plate 20, and *vice versâ*. In this way the fluctuation of velocity in the columns can be further reduced to that represented in Fig. 5, Plate 19. Here AA are the diagrams of velocity for one engine, and BB the corresponding inverted diagrams for the other engine. It will be seen that as the velocity diminishes in A, at the ends of the strokes, it increases in B, and *vice versâ*; and theoretically, the decrease and increase being the same, the resultant line of velocity in the driving column would be the horizontal full line VV. In practice this is not quite the case, and there is a rise of velocity at the ends of the strokes, as shown by the dotted line at R, R.

The double-acting engines just described were specially designed for the purpose they are applied to, which necessitated their occupying a very small space, and being very portable. But in the majority of cases, especially where the engines are applied under considerable pressure, and where the water is at all dirty, the author uses plungers instead of pistons.

An example of a pair of engines with plungers, and applied under very heavy pressure, is given in Fig. 13, Plate 22. These engines were made for pumping brine of 1·3 specific gravity from the Mansfield Company's deep salt-mine in Westphalia, and were adopted by the Company after they had had considerable experience with a similar engine applied under similar conditions. The author had nothing to do with anything beyond the engines themselves; and regrets that he is not in a position to give particulars of the accumulator, and the engines which supply it; these are however of the usual construction.

Each hydraulic engine is capable of raising per minute 66 gallons of brine 1,000 ft. high, with an effective pressure of 560 lbs. per sq. in. in the accumulator A, equivalent to 1,000 ft. head of brine. In

the larger view, Fig. 16, Plate 23, BB are the power plungers of
diam., reduced to $5\frac{1}{8}$ in. diam. in the pumping cylinders CC. The ri
and falling columns of the power water balance each other, and the
of the accumulator pressure exactly balances that of the brine i
rising main: so that the useful effect is simply given by the
between the total area of the plunger at B, and the reduced annular
at C. Hence useful effect $= \frac{8^2 - (5 \cdot 125)^2}{8^2} = 59$ per cent. The p
valves DD are precisely similar to those already described, bu
placed in separate boxes, because the power cylinders are separ
they are shown in section to a larger scale in Fig. 14, and one of
pump valves EE in Fig. 15, Plate 22. The change valve G, Fig
is worked by a tappet arrangement similar to that already descr
for the dip-engines.

The effect of fluctuations of velocity in the driving column f
an accumulator is similar to that in a column with a natural h
and the effect of enlarging the ram of the accumulator is to re
the velocity of the moving weight, in the same way as the velo
of the water is reduced by enlarging the pipe in the other c
Hence it is highly important that when an accumulator is u
it should be very large, thereby making its pulsations very slow.

As an example of the practical application of water-pres
machinery to the working of a metalliferous mine in a hilly dist
the author has prepared Figs. 17 to 25, Plates 24 to 27, wh
represent the machinery designed by him for the A. D. Lead M
near Richmond, Yorkshire.

It will be seen from Fig. 17, Plate 24, that there is a reser
situated on the hillside above the mine, at an elevation of about 50
above the adit level. Pipes are led from this reservoir down
hillside for a distance of 1800 ft., and are then taken 240 ft. dow
vertical shaft to the interior of the mine, at the inner end of the
level. At this point a large chamber is excavated, to contain
pumping and winding engines.

The pumping engine, Figs. 18 to 22, Plates 24 to 26, consist
two vertical hydraulic cylinders AA, each having a power ram 1

diameter by 7 ft. stroke. The rams are connected together by a chain passing over an overhead chain-pulley P, Fig. 21, so that one ram makes its up-stroke whilst the other is descending. A rod 3 in. diameter, fixed to the ram, passes down through a stuffing-box in the bottom of the hydraulic cylinder, and is attached to the pump-rod. The pumps are each 13 in. diameter, and of course the same stroke as the hydraulic rams. On each hydraulic cylinder is placed a valve-box B, shown in section in Fig. 22, with valves similar to those already described in connection with the other hydraulic engines; both valve-boxes are connected with a single change-valve C. The pumps, Figs. 18 to 20, are of the ordinary bucket type, provided with clack pieces, door pieces, and wind bores, such as are generally used for sinking purposes. The pumps will be used in deepening the shaft, and the hydraulic engines are proportioned for raising, at $6\frac{1}{2}$ strokes per minute, 500 gallons of water from a depth of 360 ft. to the adit level, the present depth being about 120 ft. At the full depth, with 534 ft. head on the rams, the useful effect will be represented by $\frac{13^2}{12^2-3^2}\times\frac{360}{534} = 84$ per cent.

The winding engine, Figs. 23 to 25, Plate 27, consists of a pair of double-acting hydraulic cylinders, coupled to right-angled cranks on the driving shaft, which latter is geared to the winding drum by a spur pinion: the general arrangement of the engine being very similar to that of a steam winding engine. The gearing has a proportion of 1 to 6, and the winding drum is 6 ft. diameter. The weight to be raised is 2 tons of ore at a time. The cylinders are $5\frac{1}{2}$ in. diam., 16 in. stroke, and run at $19\frac{1}{2}$ rev. per min., giving a speed of 60 ft. per min. to the rope. The admission and eduction valves are somewhat similar in construction to those already described, but are driven by means of eccentrics, having a link reversing motion, and are put in equilibrium by the somewhat novel arrangement shown in Fig. 25. The two mushroom admission valves EE are on the same spindle, on which are also fixed two pistons GG each equal in diameter to the annular eduction valves JJ. These pistons work in cylinders KK, placed beyond the engine ports, and forming continuations of the valve-box. By following out the motion of the

valves, as given by the eccentric, it will be seen that the
only to overcome the resistance due to friction, because in
the valves are balanced as regards pressures. This
considers an important improvement in this type of hyd
as it enables very large valves to be used, and thus prev
from throttling. It also enables the reversing to be do
of a link motion, and gives easy and complete control ove

Having described some examples of water-pressur
general application, the author proceeds to describe
specially designed for particular cases.

In Fig. 26, Plate 28, is shown a peculiar application o
pumping engine, and one which the author has had occasio
several instances for mining operations. At the Hutton He
near Wingate, Durham, a certain quantity of water com
strata at an intermediate point A, in a shaft where it is n
to place a pump except at the bottom. The water produ
therefore to be taken down to the bottom before being
surface. It is taken down from the point A in a d
pipe CC to the hydraulic pump B, and is delive
the delivery pipe DD to the surface; so that the work
pump is that due to the difference between 866 ft. head in
pipe and 502 ft. in the down suction-pipe, or to 364 ft
power cylinder, $6\frac{1}{8}$ in. diam., 1 ft. 3 in. stroke, is actuat
of a driving column from the point E, having an effectiv
260 ft. head. The power cylinder and pump, Fig. 27, are
acting; but the pump is a piston-pump of a peculiar
The pressure of the down suction column is const
annular space between the piston-rod, $1\frac{3}{8}$ in. dia
inside of the pump barrel, 4 in. diam. During th
delivery stroke of the pump, the pressure behind the an
the pump piston assists the plunger of the power cylin
return stroke is produced entirely by the pressure fr
suction column being brought to bear on the full fro
pump piston, the effective pressure for the return
therefore that due to the difference between the full

the pump piston and the annular area of its back face, or, in other words, to the area of the piston-rod. The useful effect is $\left(\frac{4}{6\cdot125}\right)^2 \times \frac{364}{260} = 60$ per cent. The engine is designed to work at 10½ double strokes, and to raise 7 gallons per min. It should be added that the driving water is water which would run down to the bottom of this shaft in any case, and is simply utilised for pumping.

In Figs. 28 and 29, Plate 29, is shown a pumping engine designed by the author to work under a most peculiar condition, namely that of making a single pipe serve both for the driving column of the engine and as the delivery pipe of the pump. A is the vertical pump plunger, and BB a pair of power plungers, all three coupled side by side to the same cross-head C. D is the suction valve of the pump, and E the delivery valve. F is the pipe which serves both for the delivery from the pump and for the supply to the power cylinder. It is in connection with the power cylinders at G, and has a branch H connected to the delivery valve-box above the delivery valve E. The cross-head C is of sufficient weight to cause the descent of the three plungers against the head of water in the pipe F. Water has to be pumped from the point K to the point M. The power water is obtained from the column L. J is a single-acting valve-box, similar to those already described in connection with the other hydraulic engines, and has a change valve actuated through a tappet-rod and wire by the rise and fall of the plungers.

The *modus operandi* may be thus described. During the up-stroke the plungers BB are being raised by means of the pressure in the driving column L, and water is being drawn up into the pump cylinder A through the suction valve D. On the completion of the up-stroke, the change valve in the valve-box J is reversed by the tappet-rod and wire, and the other valves are also reversed by the water itself; so that the communication to the plungers BB from the driving column L is closed, and also the suction valve D belonging to the lower sump K; while the delivery pipe to the upper sump M is opened. The weight of the cross-head C then causes the plungers to descend, forcing the water out of the pump and the power cylinders, through the pipe F, up into the sump M; and the operation is repeated in the same way. It will

thus be seen that the pipe F serves as a supply pipe to the engine during the up-stroke, and as a delivery pipe from the pump during the return stroke. This engine is specially applicable to the draining of dip workings, but can only be used to advantage in fixed positions, since it is not so portable as the other dip-working engines already described.

If a pump situated at J be substituted for the driving column L, Fig. 28, the valve-box J can be done away with, and the pipe F connected directly to the pump barrel. The dip-engine would then derive its motion from this pump, and would work simultaneously with it.

The two engines last described are of very limited application; but they present several points of interest, particularly as, in the application of water power, engineers are often called upon to devise special means in order to meet special contingencies.

The question of applying hydraulic power economically to varying resistances has received considerable attention. A very clever and ingenious device, that of automatically altering the stroke by means of a resistance governor, has been recently described in a paper before this Institution (Proceedings 1879, p. 484). There are other methods which readily suggest themselves, such as levers having shifting fulcrums, and similar devices; but the author has never found any such mechanism sufficiently practical for general application.

The dip engine already described, Plates 20 and 21, might be provided with a lever having a shifting fulcrum, between the power-cylinder and the pump; but the economy so gained, beyond that effected by the loose liner and change of piston, would not compensate for the extra complication.

In rotative engines having fly-wheels, the admission valves of the power cylinders may be made to close at varying points in the stroke, by means of known mechanisms; and if the ends of the cylinders are provided with vacuum valves opening inwards, from pipes dipping into a waste-water cistern, the speed of the engine may be kept constant, whilst the supply of pressure water is varied to meet

the varying resistances to which the engine may be applied. The cylinder would be partly filled from the pressure pipe; and then the remaining space would be automatically filled from the waste tank. By the use of three double-acting cylinders working on one crank-shaft, the portion of the stroke during which the pressure water would be admitted might be considerably varied, without causing a great fluctuation in the velocity of the driving column.

Notwithstanding the great progress which has been made in the employment of water-pressure engines, the author is of opinion that there is a wide field still open for their further application, and for the exercise of ingenuity in the perfecting of details, and in securing greater efficiency. It is mainly with a view of directing attention to a power which is somewhat neglected in this age of steam, that he has been prompted to bring this subject forward for discussion.

Discussion.

Mr. Davey exhibited a specimen of the cylindrical valve-box described in the paper, containing an annular piston-valve combined with a mushroom-valve, and showed its mode of working.

Mr. Charles Hawksley mentioned one reason for preferring water-pressure machinery in certain situations, such as for instance when employed for unwatering mines, notwithstanding the greater efficiency that might be obtained by carrying steam direct to the pump: namely that, in the event of a sudden inflow of water overpowering the pumps, the hydraulic machinery would continue to work, although drowned and inaccessible. He believed pumps of that description had been worked for several weeks, if not for months, when completely drowned.

Mr. R. H. Tweddell said the subject of the paper was one which the author had made to a certain extent his own; and he had been very successful in dealing with it. It was stated (page 245) that the author was not acquainted with any practically successful water-pressure engine working with a continuous and uniform flow; and reference was made in support of this to the rotary water-pressure engines experimented upon by Sir William Armstrong and others. He did not know whether that remark was meant to apply equally to rotative engines of such a type as the three-cylinder engine invented by Mr. Brotherhood (Proceedings 1874, page 173), or that described by Mr. Hastie in his paper read before the Institution last year (Proceedings 1879, p. 484). He should be glad to hear some explanation why rotative water-pressure engines should not be successful. He was not aware that the engines he had just mentioned had ever been applied under such circumstances as were referred to in the paper; but he knew that they had been used successfully for pumping against a head of water in an accumulator. He could not see any sensible difference between pumping against a head caused by an artificial load, such as an accumulator gave, and pumping against a head of water in an ordinary rising main from a pit. It seemed to him that an engine, which, having a single valve, was successful and acted perfectly under such conditions, was a simpler affair than one requiring such a very ingenious arrangement of double valve as that illustrated in Fig. 10, Plate 21. He had found no trouble with rotative engines working against an accumulator, and he failed to see why such engines should not be worked in connection with a common pump, and be much simpler and less liable to get out of order than when there were so many valves and valve-seats to look after.

He would not now go into the question of the efficiency of the three-cylinder engine as a steam-engine, or the efficiency of any of that class of quick-running engines. Those types of engine were for special purposes, and when suitably applied were undoubtedly efficient. In some experiments with a three-cylinder hydraulic engine, applied to drive a capstan, the efficiency came out as high as 73·7 per cent. This he considered to be a very good result, and quite equal to the

efficiency of any water-pressure engines he had ever heard of. The efficiencies given in the paper seemed to be about 65 per cent. With some pumping engines in Germany, an efficiency of 70 per cent. he believed had been reached.

The next point which had occurred to him in the paper was (page 252) as to the "effect of fluctuations of velocity in the driving column." Reference was there made to an accumulator, and it was very truly stated that the effect of enlarging the accumulator ram was to reduce the velocity of the moving weight. But he could not see what an accumulator was wanted for at the top of a brine pit, or any other pit, where the engines at the pit-bottom might just as well be driven direct by the pumps which were employed at the top of the pit for charging the accumulator. These pumps were the measure of the power imparted to the engines below, and the accumulator simply acted as a regulator between these pumps and the engines at the pit-bottom. It did not fulfil what seemed to him to be the more proper use of an accumulator, namely to meet any sudden demand, which the pumps, for the time of that demand, were not able to cope with. Under such circumstances as those illustrated in the paper he failed to see the advantage of an accumulator of any capacity.

In reference to the balanced valve shown in Fig. 25, Plate 27, it was a type of valve he had himself tried; but he had given it up on account of the trouble of keeping so many valve-seats right; and he preferred on the whole to trust to piston-valves made water-tight with hemp or leather packing. The balancing arrangement by means of a piston at the end of the valve chamber was one that he always used in his own practice, to prevent the "kick" which occurred in machines when in connection with an accumulator.

As to the question of applying hydraulic power economically against varying resistances (p. 256), he agreed with the author in his praise of Mr. Hastie's engine; but he was also sure that, except with such an absolutely automatic gear, the game was not worth the candle. Sir William Armstrong had repeatedly stated his opinion that it was not worth while in cranes to give to the men working them the means of varying the power according to the load; and he thought that was the opinion of every one who had had to do with

them. As a matter of fact, the workmen would not alter the powers in practice; the means might be given, but they would not use them. Therefore he thought, if he had a water-engine to put down, unless an automatic arrangement quite independent of the workman could be designed, he should prefer confining himself to one or two powers changed by means of ordinary clutches and gearing.

Some recognition he thought was due to one author who had written largely on the subject of utilising the water supply of the country—the late Sir Robert Kane. He had urged the matter for many years, especially in his well known work on the water supply of Ireland. The future of hydraulic engine-work for ordinary commercial purposes was a mere question of cost of working. At present there was no doubt that the competition of steam—to say nothing of gas engines—rendered it necessary to apply hydraulic engines with considerable care and judgment. He thought Mr. Davey was devoting himself to the utilisation of hydraulic pressure in a direction which promised nothing but success; while he refrained from advancing too extended a claim as to the merits of hydraulic power for small motors.

Prof. A. B. W. KENNEDY, referring to the remarks of Mr. Tweddell as to the comparative simplicity of different types of engine, observed that certainly the engine shown in Plate 21 had more than one valve, while the Brotherhood engine had only one. But although he had a great admiration for the Brotherhood engine, and had had occasion to use a great many of them, yet, if it were proposed to use one of them for the sort of work referred to in the paper, and to put it down in an inaccessible place, or in a place where, as Mr. Charles Hawksley had mentioned, it might be drowned out, then it would be a question between an engine that had a limited number of valves, and a single-valve engine having a very considerable number of connecting-rods, brasses, and bearings of various kinds, which required to be more or less looked after. In that case he thought that, putting one thing against another, for large work he should prefer to take his chance with valves, such as those described in the paper, having some knowledge that they had worked right and had not got out of

order, rather than take his chance with six connecting-rods and six pistons, three in the engine cylinders and three in the pump.

Mr. Tweddell said he only recommended using the Brotherhood three-cylinder hydraulic engine to drive an ordinary pump.

Prof. A. B. W. Kennedy observed that, if the engine were not so used, it would be necessary to have a crank and connecting-rod, or something of that kind, to drive the pump from the engine: which would come to almost the same thing. So that, from a practical point of view he should be inclined to say that, for heavy pumping work, and for anything except on a small scale, the pump described in the paper would be the one far the least likely to get out of order or to give trouble. He thought some special recognition was due to an engineer of Mr. Davey's standing, who laid before them so fully and so clearly all the details of his practice, which, as was well known, was very successful.

Mr. T. R. Crampton did not see that any air-vessels were used in the water-pressure engines described in the paper. Were they not considered necessary?

Mr. Davey replied that air-vessels were not considered necessary. They were sometimes applied; but not very often, because in such cases it would be very difficult to keep them supplied with air; and of course if they were not kept supplied with air they were of no use whatever, and only a source of danger. Again dip workings were very confined places, and an air-vessel took up considerable room—often more room than could be conveniently afforded; so that practically it was very seldom that an air-vessel was applied to those dip-working engines. It would be observed that the dip-working engine in Fig. 2 was mounted on wheels, running on a railway, so as to be moved forwards readily for following the water down. The object there was to keep the engine as light and portable as possible, and for that reason air-vessels would there be objectionable. What was aimed at in these engines was to keep the fluctuation of velocity

in the driving column as small as possible; and in that way engines were able to get on very well, without putting in large vessels, which would be very cumbersome. Speaking generally did not approve of air-vessels where high pressures were employ

Mr. CRAMPTON enquired whether, if an air-vessel were prop applied, and could be kept supplied with air, that was not m better than other mechanical appliances for the same purp particularly with a very great head.

Mr. DAVEY replied that for very great heads he preferred n use air-vessels, unless the main was also of very great le horizontally; and that for the reason he had before mentioned, in such inaccessible places the air-vessels were never attended to, in the vast majority of cases it would be found that there was n in them at all. The men who worked the engines often did visit them more than once in a month. In itself, where it could constantly attended to, and where the pressure was not great, air-vessel was no doubt the best form of regulator.

Mr. CRAMPTON said his own opinion was that in the condit mentioned by Mr. Davey the air could be supplied with ease certainty, even when the engine was drowned out, the quantity air in the air-vessel being indicated at any convenient position, any deficiency made good by simply turning on an air-tap.

Mr. T. B. LIGHTFOOT had had experience some years ago in designing of engines for draining long dip-workings, and the re he had arrived at was that steam was a much more economical mo power than water: chiefly on account of the great expense attac to the length of pipe necessary to convey the water to and f the engine. In the particular instance referred to, hydraulic p was not put down, but a small combined engine and boiler of Robey or some similar type was adopted. The valves described Mr. Davey did not strike him as presenting any special nove but they were perhaps as good a modification of the usual for could be employed.

Mr. Davey, in reply, said he thought Prof. Kennedy had disposed of Mr. Tweddell's first point, with reference to the application of three-cylinder engines for pumping; and it only remained for him to speak on the other objections raised. His great reason for using the peculiar kind of valve described in the paper was the result of his experience with slide-valves of various descriptions. In collieries and mines generally the water was not clean, and he had never found any form of slide-valve whatever that was suitable for dirty water under considerable pressures; and under the designation slide-valve he included piston-valves, and all valves with sliding surfaces. The valves now described were all lifting valves or single mitre-valves, of ordinary construction as far as the opening and closing of the valves was concerned; and they were less affected by pressure and dirty water than any valves he had had experience of. His engines had been made originally with slide-valves, and every known material had been tried for those valves, but had been found not to succeed. According to his experience, lignum-vitæ slides working on brass faces gave the best results, and he had also tried steel, gunmetal, and iron; but he never found any slide-valve that would stand the heavy pressure and dirty water to which such engines were subjected. He did not claim any great novelty in the arrangements, but, so far as he knew, he was entitled to claim the credit of so arranging the exhaust and pressure valves that they worked each other automatically, without the possibility of water slipping past. The valves tried and discarded by Mr. Tweddell, must he thought have been differently constructed; he had himself used the valve described in the paper with uniform success for several years past, and that valve he had adopted after discarding piston and other slide-valves.

As regarded Mr. Tweddell's remarks on rotative engines, it was not intended in the paper to include rotative engines, *i.e.* engines causing a rotary motion, under the term rotary engines, which meant engines having themselves a rotary, not a reciprocal motion; had that been so, he would have condemned his own designs, seeing that he had described and advocated a rotative engine in the paper, p. 253, and Plate 27. At the same time he did not consider rotative hydraulic engines the best suited for pumping.

With regard to Mr. Lightfoot's remarks as to the comparative co
of applying steam and hydraulic power in dip workings, hydrau
power was now more generally used than steam for two simp
reasons: first that the heat from steam pipes generally brought do
the roof and did much damage to the workings; and secondly that
created a very hot atmosphere in a place where there was little or
ventilation, as it was of course more difficult to ventilate dip workin
than any other part of a mine.

The ground of his bringing forward the various designs describ
was that they had been applied and had been found to work efficientl
He considered it the duty of members generally to bring forward
record of work which had been found to answer. He had mad
hydraulic engines that had not worked well, but those he had n
brought forward. It might be interesting, referring to the dip engi
shown in Plates 20 and 21, to state that the Secretary had handed hi
a letter just received from the manager of the Griff Colliery, wh
wrote as follows:—"I can speak in the highest terms as to the succe
of the hydraulic engine at the colliery. To-day our certificate
manager reports the work practically done. The dead water has bee
pumped out, and the feeder of water is under perfect control. Th
pump is now working at 11 strokes per minute with the $8\frac{3}{4}$ in
bucket;"—in other words the cylinder liner had been inserted, and
the smaller piston put on. He might remark, with regard to the dead
water, that these hydraulic engines were being used to unwater a
old dip working which had been flooded some years ago. It ha
previously been drained by steam power, but the pumps had the
been drowned out, owing to an accident, and at that time it was no
thought worth while to reopen that part of the colliery; but now i
had been determined to unwater it, and to continue getting the co
from there, using the hydraulic engines to keep down the water.

The PRESIDENT said the members could not do less than pass
hearty vote of thanks to Mr. Davey for bringing forward such
practical record of successful working. He had given his practica
experience with various water-pressure engines, and the full detail
of their construction; that was the way in which a paper ought t

The following paper was then read :—

ON ELECTRIC LIGHTING.

(*Second Paper.*)

BY DR. JOHN HOPKINSON, F.R.S., OF LONDON.

Dynamo-electric Machines.—Since the date of the author's fo
paper in April 1879, other observers have published the result
experiments similar to those described by him. It may be wel
exhibit some of these results reduced to the form he has adop
namely a curve, such as that previously shown in Fig. 4, Proceed
1879, Plate 29, and now reproduced, with slight alterations, in Fi
Plate 30. Here any abscissa represents a current passing through
dynamo-electric machine, and the corresponding ordinate repres
the electromotive force of the machine for a certain speed of revolu
when that current is passing through it. It will be found (1) that
varying speed the ordinate, or electromotive force, correspondin
any abscissa or current, is proportional to the speed; (2) that
electromotive force does not increase indefinitely with increa
current, but that the curve approaches an asymptote; (3) that
earlier part of the curve is, roughly speaking, a straight line,
the current attains a certain value, and that at that point
electromotive force has reached about two-thirds of its maxi
value. When the current is such that the electromotive force i
more than two-thirds of its maximum, a very small change in
resistance with speed of engine constant, or in the speed of
engine with resistance constant, causes a great change in the cur
For this reason the greatest of these currents, which is
corresponding to the point where the curve breaks away fr
straight line, and which is the same for all speeds of revolu
since the curves for different speeds differ only in the sca

rdinates, may be called the "critical current" of the machine. The effect of a change of speed is exhibited in Fig. 1, where the lower dotted line represents the curve for a speed of 660 revolutions per minute, instead of 720. The resistance, varying as $\frac{\text{electromotive force}}{\text{current}}$, is given by the slope of the line OP. But since the resistance is constant, the slope of this line must be constant; and it will be seen that it cuts the upper curve at a point corresponding to a current of 15 webers, and the lower at a point corresponding to a current of 5 webers only.

In Germany, Auerbach and Meyer (Wiedemann's Annalen, Nov. 1879) have experimented fully on a Gramme machine at various speeds, and with various external resistances. The resistance of the machine was 0·97 ohms. Their results are summarised in a Table at the end of their paper, which gives the current passing, with resistances in circuit from 1·75 to 200 Siemens units, and at speeds from 20 to 800 revolutions per minute. In the accompanying diagram, Fig. 2, Plate 30, the curve G expresses the relation between electromotive force and current, as deduced from some of their observations; the points marked are plotted from their Table, making allowance, where necessary, for difference in speed. The curve, as actually constructed, is for a speed of 800 revolutions: at this speed it will be seen that the maximum electromotive force is about 76 volts; and the critical current, corresponding to a force of about 51 volts, is 6·5 webers, with a total resistance of 7·8 ohms. Up to this point there will be great instability, exactly as was the case in the Siemens machine examined by the author, where the resistance was 4 ohms, and the speed 720 revolutions.

The results of an elaborate series of experiments on certain dynamo-electric machines have recently been presented to the Royal Society by Dr. Siemens. One of the machines examined was an ordinary medium-sized machine, substantially similar to that tried by the author in 1879. It is described as having 24 divisions of the commutator; 336 coils on the armature, with a resistance of 0·4014 Siemens units; and 512 coils on the magnets, with a resistance of 0·3065; making a total resistance of 0·7079 Siemens units

= 0·6654 ohms. The curve Sm, Fig. 2, gives the r
electromotive force and current, reduced to a speed of 70
minute, the actual speeds ranging from 450 to 800 r
maximum electromotive force appears to be probably 76
the critical current 15 webers: which is the same as in th
first experiments on a similar machine.

In the summer of 1879 the author examined a Siemen
of the smallest size. This machine is generally sold as
for their alternate-current machine. It has an internal res
0·74 ohms, of which 0·395 is in the armature or helix. Th
is marked to run at 1130 rev. per min. The following
gives, for a speed of 1000 rev., the total resistance,
electromotive force, and horse-power developed as curr
horse-power expended was not determined.

TABLE II.—EXPERIMENTS ON SMALLEST-SIZED SIEMI
DYNAMO-ELECTRIC MACHINE.

Resistance.	Electric Current.	Electro-motive Force.	Horse-power developed as current.
Ohms.	Webers.	Volts.	H. P.
2·634	5·10	13·2	0·09
2·221	12·15	27·0	0·44
1·967	17·0	33·6	0·76
1·784	20·4	36·4	0·99
1·668	22·3	37·2	1·11
1·579	23·2	36·6	1·14
1·503	25·6	39·3	1·34
1·440	27·8	40·0	1·49
1·145	36·2	41·5	2·00

The curve Ss, Fig. 2, gives as usual the relations of elec
force and current. From this curve it will be seen that t
current is 11·2 webers, and the maximum electromotive

the speed of 1000 rev., is about 42 volts. The determinations for this machine were made in exactly the same manner as in the experiments on the medium-sized machine, using the galvanometer, but omitting the experiment with the calorimeter (compare Table I., page 249, Proceedings 1879).

The time required to develop the current in a Gramme machine has been examined by Herwig (Wiedemann, June 1879). He established the following facts for the machine he examined. A reversed current, having an electromotive force of 0·9 Grove cells, sufficed to destroy the residual magnetism of the electro-magnets. If the residual magnetism was as far as possible reduced, it took a much longer time to get up the current than when the machine was in its usual state. A longer time was required to get up the current when the external resistance was great, than when it was small. With ordinary resistance the current required from $\frac{3}{4}$ second to 1 second to attain its maximum.

Brightness of the Electric Arc.—The measurement of the light emitted by an electric arc presents certain peculiar difficulties. The light itself is of a different colour from that of a standard candle, in terms of which it is usual to express luminous intensities. The statement, without qualification, that a certain electric lamp and machine give a light of a specified number of candles, is therefore wanting in definite meaning. A red light cannot with propriety be said to be any particular multiple of a green light; nor can one light, which is a mixture of colours, be said with strictness to be a multiple of another, unless the proportions of the colours in the two cases are the same. Captain Abney (Proceedings of the Royal Society, 7 March 1878, p. 157) has given the results of measurements of the red, blue, and actinic light of electric arcs, in terms of the red, blue, and actinic light of a standard candle. The fact that the electric light is a very different mixture of rays from the light of gas or of a candle, has long been known, but has been ignored in statements intended for practical purposes.

Again, the emission of rays from the heated carbons and arc is by no means the same in all directions. Determinations have been

made in Paris of the intensity in different directions, in particular cases. If the measurement is made in a horizontal direction, a very small obliquity in the crater of the positive carbon will throw the light much more on one side than on the other, causing great discordance in the results obtained.

If the electric light be compared directly with a standard candle, a dark chamber of great length is needed—a convenience not always attainable. In the experiments made at the South Foreland by Dr. Tyndall and Mr. Douglass, an intermediate standard was employed; the electric light was measured in terms of a large oil lamp, and this latter was frequently compared with a standard candle.

Other engagements have prevented the author from fairly attacking these difficulties; but since May 1879 he has had in occasional use a photometer with which powerful lights can be measured in moderate space. This photometer is shown in Figs. 3 and 4, Plate 31, and an enlargement of the field piece in Fig. 5. A convex lens A, of short focus, forms an image at B of the powerful source of light which it is desired to examine. The intensity of the light from this image will be less than that of the actual source by a calculable amount, and when the distance of the lens from the light is suitable, the reduction is such that the reduced light becomes comparable with a candle or a carcel lamp. Diaphragms CC are arranged in the cell which contains the lens, to cut off stray light. One of these is placed at the focus of the lens, and has a small aperture. It is easy to see that this diaphragm will cut off all light entering from a direction other than that of the source; so effectually does it do so, that observations may be made in broad daylight on any source of light, if a dark screen be placed behind it. The long box EE, Fig. 3, of about 7 ft. length, is lined with black velvet,—the old-fashioned dull velvet, not that now sold with a finish, which reflects a great deal of the light incident at a certain angle. This box serves as a dark chamber, in which the intensity of the image formed by the lens is compared with a standard light, by means of an ordinary Bunsen's photometer F, sliding on a graduated bar.

Mr. Dallmeyer kindly had the lens made for the author: he can therefore rely upon the accuracy of its curvature and thickness; it is plano-convex, the convex side being towards the source of light. The curvature is exactly 1 in. radius and the thickness is 0·04 in.; it is made of Chance's hard crown glass, of which the refractive index for the D line in the spectrum is 1·517. The focal length f is therefore 1·933 inch.

Let u denote the distance of the source of light from the curved surface of the lens, and v the distance of the image B of the source from the posterior focal plane. Neglecting for the moment loss by reflection at the surface of the glass, the intensity of the source is reduced by the factor $\left(\frac{v}{u}\right)^2$. But $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$, or $v=\frac{uf}{u-f}$; hence the factor of reduction is $\left(\frac{f}{u-f}\right)^2$. The effect of absorption in so small a thickness of very pure glass may be neglected; but the reflection at the surfaces will cause a loss of 8·3 per cent., which must be allowed for. This percentage is calculated from Fresnel's formulæ, which are certainly accurate for glasses of moderate refrangibility, and for moderate angles of incidence.

Suppose, for example, it is required to measure a light of 8000 candles; if it be placed at a distance of 40 in., it will be reduced in the ratio 467 to 1, and becomes a conveniently measurable quantity. By transmitting through coloured glasses both the light from an electric lamp and that from the standard, a rough comparison may be made of the red or green in the electric light with the red or green in the standard.

A dispersive photometer, in which a lens is used in a somewhat similar manner, is described in Stevenson's "Lighthouse Illumination;" but in that case the lens is not used in combination with a Bunsen's photometer, nor with any standard light. Messrs. Ayrton and Perry described a dispersive photometer with a concave lens at the meeting of the Physical Society on 13th December 1879 (Proceedings Physical Society, vol. iii., p. 184). The convex lens possesses however an obvious advantage in having a real focus, at which a diaphragm to cut off stray light may be placed.

Efficiency of the Electric Arc.—To define the electrical condition of an electric arc, two quantities must be stated—the current passing, and the difference of electric potential at the ends of the two carbons. Instead of either one of these, we may, if we please, state the ratio $\frac{\text{difference of potential}}{\text{current}}$, and call it the resistance of the arc, that is to say, the resistance which would replace the arc without changing the current. But such a use of the term electric resistance is unscientific; for Ohm's law, on which the definition of electric resistance rests, is quite untrue of the electric arc; while on the other hand, for a given material of the electrodes, a given distance between them, and a given atmospheric pressure, the difference of potential on the two sides of the arc is approximately constant. The product of the difference of potential and the current is of course equal to the work developed in the arc; and this, divided by the work expended in driving the machine, may be considered as the efficiency of the whole combination. It is a very easy matter to measure these quantities. The difference of potential on the two sides of the arc may be measured by the method given by the author in his previous paper, or by an electrometer, or in other ways. The current may be measured by an Obach's galvanometer, or by a suitable electro-dynamometer, or best of all, in the author's opinion, by passing the whole current, on its way to the arc, through a very small known resistance, which may be regarded as a shunt for a galvanometer of very high resistance, or to the circuit of which a very high resistance has been added.

It appears that with the ordinary carbons, and at ordinary atmospheric pressure, no arc can exist with a less difference of potential than about 20 volts; and that in ordinary work, with an arc about $\frac{1}{4}$ in. long, the difference of potential is from 30 to 50 volts. Assuming the former result, about 20 volts, for the difference of potential, the use of the curve of electromotive forces may be illustrated by determining the lowest speed at which a given machine can run, and yet be capable of producing a short arc. Taking O as the origin of co-ordinates, Fig. 6, Plate 31, set off upon the axis of ordinates the distance OA equal to 20 volts; draw AB to

intersect at B the negative prolongation of the axis of abscissæ, so that the ratio $\frac{OA}{OB}$ may represent the necessary metallic resistance of the circuit. Through the point B, thus obtained, draw a tangent to the curve, touching it at C, and cutting OA in D. Then the speed of the machine, corresponding to the particular curve employed, must be diminished in the ratio $\frac{OD}{OA}$, in order that an exceedingly small arc may be just possible.

The curve may also be employed to put into a somewhat different form the explanation given by Dr. Siemens at the Royal Society, respecting the occasional instability of the electric light, as produced by ordinary dynamo-electric machines. The operation of all ordinary regulators is to part the carbons when the current is greater than a certain amount, and to close them when it is less; initially the carbons are in contact. Through the origin O, Fig. 7, Plate 31, draw the straight line OA, inclined at the angle representing the resistances of the circuit other than the arc, and meeting the curve at A. The abscissa of the point A represents the current which will pass if the lamp be prevented from operating. Let ON represent the current to which the lamp is adjusted; then if the abscissa of A be greater than ON, the carbons will part. Through N draw the ordinate BN, meeting the curve in the point B; and parallel to OA draw a tangent CD, touching the curve at D. If the point B is to the right of D, or further from the origin, the arc will persist; but if B is to the left of D, or nearer to the origin, the carbons will go on parting, till the current suddenly fails and the light goes out. If B, although to the right of D, is very near to it, a very small reduction in the speed of the machine will suffice to extinguish the light. Dr. Siemens gives greater stability to the light by exciting the electro-magnets of the machine by a shunt circuit, instead of by the whole current.

The success of burning more than one regulating lamp in series depends on the use in the regulator of an electro-magnet, excited by a high-resistance wire connecting the two opposed carbons. The force of this magnet will depend upon the difference of potential in the arc, instead of depending, as in the ordinary lamp, upon the current

passing. Such a shunt magnet has been employed in a variety of ways. The author has arranged it as an attachment to an ordinary regulator; the shunt magnet actuates a key, which short-circuits the magnet of the lamp when the carbons are too far parted, and s causes them to close.

In conclusion the Author ventures to remind engineers of the following rule for determining the efficiency of any system of electr lighting in which the electric arc is used, the arc being neith exceptionally long nor exceptionally short. Measure the differen of potential of the arc, and also the current passing through it, volts and webers respectively; then the product of these quantiti divided* by 746, is the horse-power developed in that arc. It then known that the difference between the horse-power develop in the arc and the horse-power expended to drive the machi must be absolutely wasted, and has been expended in heating eith the iron of the machine or the copper conducting wires.

Discussion.

Mr. J. N. Shoolbred thought the present paper showed the value the method adopted by Dr. Hopkinson in his first paper, for analysi and representing his experiments; inasmuch as the experiments other persons, with other machines, and also with the Siem machine, had been reduced on that method, and could thus compared together. He wished to refer to another curve, Fig. Plate 30, which formed a diagram of experiments with a Gram machine, carried out last year, at the India-Rubber, Gutta-Perc and Telegraph Works at Silvertown, by Mr. R. K. Gray, communicated to himself by that gentleman. The value of the form giving results, which Dr. Hopkinson had explained to the Institut in his first paper, was acknowledged by Mr. Gray, and experiments had in a great measure been carried out on the sa

* See additional explanation in discussion, p. 283.

lines. It might therefore be interesting to lay them before the meeting reduced to a curve in the same form that Dr. Hopkinson had adopted; by that means the results could be compared of two machines—the medium-size Siemens and the A-size Gramme machine—which were generally looked upon as machines of pretty nearly equal efficiency. He did not know whether the curve of Auerbach and Meyer (G Fig. 2), which was for a Gramme machine, referred to the A size of machine or not; perhaps Dr. Hopkinson would state this. With regard to the diagram, Fig. 8, of the Silvertown experiments, which had been carried out on 23rd July of last year on machine No. 368, he might draw attention to the remarkable similarity of the greater portion of it to the curve shown by Dr. Hopkinson in Fig. 1. The larger amount of electromotive force which was shown by the Gramme machine was due no doubt to its higher speed—1000 revolutions against 720 with the Siemens machines—as well as to the mode of construction of the machine itself. The Thomson galvanometer and the resistance coils used were those ordinarily employed in the frequent electrical testing which took place in those works.* The resistance of the machine when cold was 1·09 ohms,

* The following information has been received in a letter from Silvertown since the date of the meeting:—"The results of the tests made on the A Gramme machine, No. 368, to ascertain the electromotive force with different interpolar resistances, were obtained from the fall of potential between two points in the closed circuit, by charging a condenser between these points and observing the discharge through a Thomson's reflecting galvanometer: several discharges being recorded, and the mean used for calculation. The points between which the difference of potential was observed were the brushes attached to the ends of the generating or armature coil, the resistance of which, as well as that of the field-magnet coils and interpolar resistance, was measured immediately after each experiment in order to ascertain the actual resistance of the wire when heated by the current. This being of material importance, especially when the external resistance is small, the machine was allowed to run for some little time, to let the heating of the coils take full effect and become tolerably constant. Knowing therefore the resistance of the field-magnet coils and interpolar resistance, and also that of the generating coil at the time when the difference of potential between the two brushes was measured, the total electromotive force has been worked out and expressed in volts by comparison with the discharge from two Leclanché cells, the electromotive force

increasing to 1·17 ohms at the termination of the experiments. Th results of these experiments were presented, as worked out Silvertown, in the following Table, the form of which was similar that adopted by Dr. Hopkinson in his paper last year (see Proceedin Inst. M.E. 1879, p. 249): the actual speeds of the experiments we here reduced throughout to 1000 revolutions per minute.

Experiments on Gramme Dynamo-Electric Machine, **A** *size, No.* 3 *carried out at Silvertown* 23 *July* 1879. (Fig. 8, Plate 30.)

No. of Experiment.	Total Resistance of Circuit. R	Electric Current. Q	Electro-motive Force. E	Work measured per second. By Galvano-meter. W_1	Work measured per second. Equivalent Horse-power.	Revs. Armat per minu n
	Ohms.	Webers.	Volts.	Erg-tens.	H.-P.	Rev
1	19·82	0·36	7·10	0·003	0·003	100
2	15·09	0·62	9·41	0·006	0·008	,,
3	9·83	6·42	63·09	0·40	0·54	,,
4	8·91	8·09	72·07	0·58	0·78	,,
5	7·94	9·24	73·39	0·68	0·91	,,
6	7·03	11·68	82·11	0·96	1·29	,,
7	5·86	15·04	88·14	1·33	1·78	,,
8	4·96	20·14	99·88	2·01	2·70	,,
9	3·96	24·85	98·44	2·45	3·28	,,
10	3·05	30·07	91·71	2·76	3·70	,,
11	2·13	44·94	95·73	4·30	5·77	,,

of a Leclanché cell being taken as 1·61 volts. When the interpolar resist was over 4 ohms, it consisted of carbon rods 0·496 inch diameter and 19 in long, joined up in series; and for resistances less than 4 ohms, of coil indiarubber-covered nineteen-strand copper wire, 0·155 inch diameter. number of revolutions of the generating coil per minute was taken velocimeter direct from the spindle of the armature, so that the number indic could not be affected by the strap slipping. The fall therefore in the electrom force cannot be attributed to this, but is we believe due to the magnetism of field magnets falling off after the external resistance has been reduced bey certain point; and is in effect somewhat analogous to the action in a batter to polarisation. This effect would be produced in a Siemens machine, only the external resistance had been still further reduced than in the case Gramme machine, since the former has a much lower resistance than the la

He would ask Dr. Hopkinson kindly to give some further explanation with regard to what he called the critical current, to which it was evident he attached great importance.

The subject of photometers and standards of light was one of great importance for the electric light and for all large sources of light. The extreme inconvenience of the methods which had hitherto been used, with the standard sperm candle, had forced itself upon the notice of many observers, and had been commented upon very ably by Mr. Preece a short time back (Proc. Society of Telegraph Engineers, 1880, p. 162). A very valuable rule was given in page 274 of the paper as to the effective horse-power developed in the electric arc: namely that it was the product of the difference of potential and of the current, divided by 746. He would ask how the divisor 746 was arrived at as this was a matter of considerable practical importance.

He might direct the attention of members to the very important results stated by Dr. Siemens before the Royal Society, and alluded to in the paper, as to his new arrangement for dividing the current emanating from the coils, according to the suggestion of Sir Charles Wheatstone. By sending a portion of the current back again to the exciting magnet, and making use of the remainder alone for duty in the electric arc, he obtained much greater regularity in the work done, as well as a very sensible diminution in the destructive effect which the machine exercised upon itself. Those two improvements would be of very great importance in future machines of that kind.

Mr. R. E. B. Crompton desired to point out the practical effect of the two very different curves given by the two classes of machines that were so commonly brought into rivalry, namely the A Gramme and the Siemens medium machine, which in Fig. 2, Plate 30, were represented by the curves G and Sm respectively. The A Gramme machine, it would be seen, had very high electromotive force, and much the best current of the two. The consequence was it could be practically used with a much thinner leading wire, and the cost of the cables was thus greatly reduced. But against this must be set the fact that the lamps could not be kept burning steadily with so short an arc as in the Siemens machine. Now the length of

the arc was the one thing which ruled the question, whether the electric light would become popular or not. A long arc invariably disgusted everybody who had been accustomed to a white light; it varied constantly from purple to violet, and assumed all kinds of ghastly colours. In a manufactory this was not so important; moreover with a long arc there was not the same fear of destroying the insulation of the machine. As engine-drivers were sometimes incautious, and governors not very good, and as a long arc, though not giving so stable a light, left greater margin for variations in speed, without risk of damaging any part of the apparatus, it was better to use the longer arc wherever the light was employed simply as an adjunct to a factory. He believed he was right in saying that, with the short arc used in the Siemens machine, much more careful attention had to be given to the regulation of the lamp, and workmen of a higher class had to be employed on the machine.

If Dr. Hopkinson's diagram, Fig. 6, Plate 31, was correct, as no doubt it was, the problem was solved which had perplexed him for a long time, namely to find out the point at which to regulate the lamps in order to get stability of light. But Mr. Shoolbred had set before them another curve, Fig. 8, Plate 30, to which, owing to the inflection at the upper part, he found it rather difficult to apply the method shown in the diagram, Fig. 6. It appeared to him that there would be two regions of instability in that diagram; and in that case a lamp could never be got to burn steadily. He though the apparent fall in the electromotive force, after attaining it maximum, must be due to some mistake.

The next point to which he wished to call attention was the photometer. Nothing could really be done with the electric lig without a good photometer, as everybody connected with it wou admit. What was wanted however was not a photometer to be used li a telescope in a horizontal direction only, but something to measu the light as it fell in practice upon books or papers, generally at considerable angle, say 60° from the vertical. The lamps were put as high as possible, and were generally spaced at such a distance ap that the light fell at somewhere about that angle. But the photome described in the paper could not be turned upwards at such

gle, to shoot the light down into the standard candle, because the me of the candle would keep perpendicular, and every time the gle was altered the distance would also be altered between the itre of the candle flame and the photometer slide. In practice at was wanted was an instrument for rough measurement only, ich could be taken into a railway station, and enable an opinion to formed as to whether there was sufficient light to suit people. ith this object he proposed to divide the light into a certain mber of standards, say three. The first would be the best for ists, engravers, or fine work of any kind; the second standard uld be such as was required for railway stations and large buildings that class; and the third for outdoor work, such as contractors' avations. Each standard might be represented by the angular tance of a standard candle from a plane surface placed below it at ordinary angle. He had designed a photometer to work on t principle, as shown in Figs. 9 and 10, Plate 32. It consisted a stereoscope A, in which, in place of the usual slide, was fitted a de B formed of blotting-paper ruled with fine lines of spermaceti oil. A lamp C, of which the flame could be raised or lowered, s placed behind the slide, and threw a strong light on its under rface. The two lights to be compared reached the upper surface the slide through the telescopic tubes D E. The photometer ing placed on its tripod stand was swung round, and the two tubes, hich were hinged at H, were raised at an angle by an adjusting rew, until the light to be observed was directed fairly upon the lide through the tube E. The back light C was then increased or iminished until it balanced the observed light: this was ascertained y noticing the point at which the oiled lines on the slide changed rom dark to light. The standard candle or lamp F in the other lescopic tube D was then moved in or out until its light also alanced that of the back lamp C. The intensities of the standard ght and of the observed light were then equal, and their distances om the centre diaphragm of the stereoscope could be measured and mpared. Or the standard light might first be balanced with the ck lamp, and the photometer moved bodily nearer or further from observed light, until this also balanced the back lamp as before.

If the first standard were represented by the light of a sta
candle placed 1 foot from the surface of the slide, then the hori
distance of the photometer from a plumb line let fall from
observed light would be the radius of the circle which would
illuminated by the observed light up to that standard. In
photometer, as the observer looked simultaneously and directly a
surfaces illuminated by the two lights, their difference coul
observed more accurately than where a Bunsen diaphragm was
which must be observed either by inclined reflectors or by pr
In either case light was lost, and error thus crept in. Except
colour, which was a difficulty not easily got over, a very
approximation could be obtained by the method he had desc
Dr. Hopkinson seemed to consider it inaccurate to speak of compa
measurements of the electric light and other lights, because
difference in the colours; but he did not see how that difficulty
be overcome. If electric light and gaslight were to be used,
must be brought into comparison somehow, and the light mu
judged of by the power it gave of distinguishing small objects.
such a purpose he thought the photometer which he proposed
sufficiently good.

With regard to the paragraph in the paper, p. 273, which ref
to burning regulating lamps in series, the easiest way of doing
was simply to wind the lamp electro-magnets with fine wire ou
the ordinary wire, and pass a shunt current through this fine
in the opposite direction to the arc current. The fine wire f
nicely between the coils of the large wire, and made a very
job, with very slight extra expense for the lamp.

Mr. W. H. Preece said Mr. Crompton's remarks on photome
induced him to bring before the notice of the meeting some experim
that he had recently been making in photometry. The great diffic
in all these measurements was that pointed out in the paper, nam
the difference in the colour of the lights. The great desidera
therefore was a photometer which would be independent of col
Neither Dr. Hopkinson nor Mr. Crompton had got over the difficu
but some assistance might be obtained from one of the very

principles ever introduced into photometry. It was introduced by a French physicist of the name of Bouguet, who was very little known, and who lived some 100 years ago. He showed how it was possible to measure light to a certain extent independently of colour. Take the case of a rope hanging near a wall, with two equal lights, one directly in front of it, and the other at one side. The rope threw a shadow upon the wall from each light, and it would be seen at once that the intensity of the shadow from the side light was very much less than the intensity of that from the central light: and if it were possible to move the central light nearer, there would be found a point where the side shadow would disappear entirely. When that point was reached, the ratio of the squares of the distances of the two lights from the wall would be the ratio of their intensities measured at the wall. If, instead of the wall and the two lights, a white surface, such as a sheet of paper, was used, and a standard candle or a London Argand burner, which he believed to be the best standard burner, then the apparatus might be taken to any part of a room illumined by an electric light, and the intensity of the light at that place might be ascertained. The important thing to know was, not the intensity of the light up at the ceiling, but the intensity down on the floor, where people sat. For measuring the lighting of a room or a railway station, a white disc could be placed against the wall, with a small copper rod to throw a shadow upon the disc from a moveable standard lamp; then very little adjustment of the lamp would enable the point to be found where that shadow disappeared, whence a relation could be obtained between the standard lamp and the light used in the room. He had been experimenting on this method with very satisfactory results; but he was not quite sure that the principle worked perfectly true, *i.e.* that the shadow actually did disappear, although to the eye it practically seemed to disappear. Even that kind of photometer was not independent of one great cause of the variations which existed in the measurements of light, namely the want of uniformity in the human eye. Thus, if several measurements of the same light were taken by different observers, it would be found that they all differed by a very considerable amount; in fact he had known careful measurements of the same light, made by different people, which varied between

250 candles and 1200 candles. Such a result showed in the fin that the apparatus now used for measuring light was very imp and secondly that it was used by means of another instrum human eye, which was also imperfect.

Mr. JOHN PERRY, referring to the statement on p. 271, with to the photometer used by Professor Ayrton and himself h concave lens, said that of course they had known that a con would serve quite as well for the purpose required, which wa a very divergent cone of rays from a very small pencil of lig concave or a convex lens might be used for that purpose, and he see that there could be very much difference in the accuracy divergence; but they had chosen a concave lens, because thinner, and therefore there would be less absorption of light glass. Dr. Hopkinson however was in a much better positio what the absorption would be than Mr. Ayrton and himself. the concave lens the instrument was also shorter, by just tw focal length.

With regard to the measurement of light in various dir that form of photometer could be easily arranged for any direction than horizontal. It would simply be necessary to the relative inclination of the two parts of the instrument, so t screen which was illuminated by the standard candle still re vertical, while the screen which was illuminated by the rays fr source of light was placed at right angles to the direction o rays, whatever that direction might be.

Mr. KILLINGWORTH HEDGES hoped on another occasion to d some experiments he had lately been making on carbons. H agreed with Mr. Crompton, that very often, although a sh was the best, engineers were obliged to use a long one: and t way of getting over the difficulty of colour was to prepare the c either by coating them, or by mixing some substance with which, becoming incandescent, would give out rays that neutralise, to a large extent, the blue colour conside objectionable.

Dr. HOPKINSON thought the inflection at the top of the curve in Fig. 8, Plate 30, must be due to some uncorrected error of observation, which might easily remain undetected owing to the small number of xperiments recorded; he did not think it was physically possible that he curve should have that form with a constant speed of rotation.

In reference to the size of the Gramme machine used by Auerbach nd Meyer for the experiments shown in the curve G, Fig. 2, they d not described it as an A or a B machine, but had stated its ectrical resistance as 0·97 ohm. That probably would be the best scription of the machine, with a view of comparing it with any her Gramme machine. As to the critical current, what he had itten really amounted simply to this: that, roughly speaking, the rve showing the connection between the electromotive force and e current rose approximately in a straight line at first, and then rved off, as far as he could judge, towards a horizontal asymptote, e straight line continuing to about two-thirds of the height of the rizontal asymptote. He thought therefore it was convenient, in scribing the machine, to take the current which he had called the itical current as the definition of the distance to which the curve n in a straight line before it became curved. Practically the current as unstable whenever it was below that point.

With respect to the factor 746, given on p. 274, the product of ifference of potential and current was power, which could of course e given as so many foot-pounds per minute; but the number that as got by multiplying webers and volts together did not give the ower in foot-pounds, and it required a factor to reduce the one to he other, just as it required a factor to reduce gramme-centimetres, r any other measure of power, to foot-pounds. The factor in this ase happened to be 746, as would be seen by referring to Everett, 'Units and Physical Constants." The product of a weber and a olt was 10^7 ergs per second (p. 138), whilst a horse-power was $7{\cdot}46 \times 10^9 = 746 \times 10^7$ ergs per second (p. 25); hence the rule given.

With regard to Mr. Crompton's remark on the comparison of the A Gramme machine, curve G, Fig. 2, with the Siemens medium-sized machine, curve Sm, Fig. 2, he thought the fact really was that the

the first place, all the ordinates would be higher, an
therefore approach a higher asymptote. In the sec
to the winding of the magnets with a larger num
whole curve would be made steeper, the electrom
more rapidly in proportion to the current. Thus
curve would rise more quickly towards a greater
and the consequence would be that in the angle a
would approximate to the curve G of the Gramm
would rise to a greater height. The medium-sized
was really a machine of greater power than the A
To drive it with its ordinary currents he felt
required higher horse-power; and consequently a
energy could be actually devoted to the arc with th
machine than with the A Gramme machine.

He had had some experience with the Siemens
it working in the hands of a mere labourer, who
engine that drove it, and had no trouble with it
had taken very great care to have the engine
governed before starting. He believed that the
engines was the cause of half the trouble experie
with any other electric light.

With regard to the photometer, he did not th
serious difficulty in adapting it to measure light at

In reference to the question how the electric light was to be described if not in standard candles, he would propose simply to say that a given electric light contained so many times as much of a given kind of red or blue light as a standard candle. When light was spoken of as given by an electric lamp or by a candle, the same word was applied to two different things which could not be correctly compared with each other.

With regard to Mr. Preece's shadow photometer, he did not think that it was entirely independent of colour. Though probably for any one observer it would be so, it seemed to him exceedingly probable that different observers would obtain different comparative results. With regard to the convex and concave lens mentioned by Mr. Perry, he did not think the absorption, in a lens of the thickness required in either case, was any sensible quantity; and for that reason he still thought that the best plan was to adopt a convex lens, so as to be able to put in a diaphragm at the proper place, and cut off all stray light.

The President proposed a vote of thanks to Dr. Hopkinson for his paper, which was carried by acclamation.

The President proposed a vote of thanks to the Institution of Civil Engineers for their kindness in allowing the members the use of their room.

The motion was carried unanimously.

The Meeting then terminated.

ON THE MANUFACTURE OF STEEL, AND THE MODE OF WORKING IT.

BY D. CHERNOFF.

(Read before the Imperial Russian Technical Society, April and May, 1868.

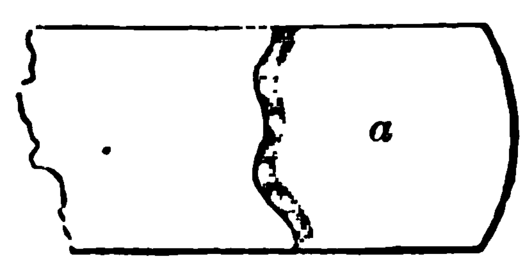
TRANSLATED BY MR. WILLIAM ANDERSON, OF ERITH,
AND REPRINTED BY THE AUTHORITY OF THE COUNCIL.

Steel, as generally used in the arts, is a combination of iron carbon. The purer these elements in steel, the higher are qualities. The best steel that has ever been made in any ag country is, without question, 'boulat' (the sabre steel of Tartars). The special qualities of 'boulat,' and especially markings appearing on its surface, have sent many investigator a wrong scent; all thought to find the extraordinary qualitie this steel in some special mixtures. Careful analyses have b made, but, to the surprise of all, nothing has been found compet to explain the presence of the characteristic veining. Inasmuch the veining of 'boulat' is closely connected with its quality, it attempted to find substances which, being melted with the st would produce the markings required. Steel was melted w various metals, with platinum, silver, and so on, and veinin were, no doubt, produced; but in the first place, they were far fr having the same regularity and beauty, and secondly, as well chiefly, the steel produced was always inferior to 'boulat.' T peculiarity of the veining of 'boulat' lies also in this, that if y heat a good specimen of the steel with clearly-marked veining a bright red heat, and then allow it to cool, it will be impossi to restore the markings, no matter how long you treat the surfa with acid. The veining, on the other hand, produced by t mixture of metals never disappears, however much the steel m be heated. But if the piece of 'boulat' in which the veining h

disappeared be melted again, then, if certain conditions in the cooling of the ingot are observed, the veining appears again, though of a somewhat different design; and in this manner it is possible to produce or annihilate the pattern several times. The investigations of Anosoff have clearly shown that the problem is solved in the purity of the steel, and he has succeeded, as is well known, in producing the very highest qualities of Eastern 'boulat.'

On a former occasion I spoke of the observations I had made on the ribbons of dead tint observable on the surfaces of steel guns in the lathe. By means of careful daily records of the forging of the gun ingots, I found that these tints appeared in the boundaries between the hot and the cold portions of the ingot being forged; that is to say, always at those points up to which the ingot was pushed into the furnace. The position and appearance of the strips of dead tint always coincided with the position and form of the limit of heating. If a spot so noted by me was afterwards reheated, then the ribbon of dead tint no longer appeared after turning in the lathe. Besides this, some of these ribbons would disappear as a greater or less thickness of metal was turned off; others penetrated right through the mass of the gun, and never disappeared.

It is further remarkable, that although, at times, the transition from the heated to the cold portion of the ingot was so gradual that it was impossible to assign any limit, yet the ribbon of dead tint developed by the turning of the surface of gun, and corresponding to the above ill-defined limit of heating, was so clearly marked, that it was easy to trace its boundaries with a pencil on the surface of the gun. It must be remarked also that



the ribbon has only one well-defined margin, that which was turned towards the cold end of the ingot; the other margin is shaded off imperceptibly into the normal tint *a* of the steel.

Wishing to investigate the effects of the steam hammer on t structure of steel, I heated a 4½-inch ingot to a bright red colo and subjected it to two heavy blows of a 5-ton hammer, so t one-third the length was not touched at all, the second third flattened to 3 inches, and the last received two cross blows, un each of which there was a compression of at least 1½ inch. T ingot was then left to cool in the open air, and on being broke was found that the appearance of the structure of each of the th sections remained identical, not only to the naked eye, but to most careful microscopical examination.

I have also drawn attention to the circumstance that, on occasion, when experimenting on the influence of the tempera to which steel was heated on its hardness in tempering ordered a smith to heat a piece of steel to dull red, but he, mistake, heated it bright red. Wishing to rectify the error, I not at once plunge the steel into water, but let it first cool d to dull red, and then immersed it. Although the steel was quality capable of extreme hardness in tempering, the immer not only did not make it hard, but actually made it sensi softer. I have recalled the above circumstances because, connection with many others, they induced me to investigate influence of temperature on steel, and formed points of depart for my researches. Space will not allow of my describing experiments in detail. I must content myself with stating conclusions to which I have arrived.

If steel melted in a crucible is constantly kept in viol agitation while cooling, agitation violent enough to keep all particles in motion, then the cold ingot produced will have a v finely crystallised structure; if, on the other hand, the melted s is allowed to cool in perfect quiet, then the resulting casting consist of large well-developed crystals. The appearance of th crystals, and generally the tendency to crystallise under th circumstances, will depend on the purity of the steel. As I h already stated, the ultimate purity of the steel consists in t of its two component elements, iron and carbon, and the best s is composed of only these two elements.

With reference to other elements, the presence of which is supposed to influence the quality of steel, it is impossible to avoid mentioning the opinion of Fremy, who considers nitrogen so essential, not only to the formation, but to the very existence of steel, that he has laid down the proposition that "if the nitrogen is taken away from steel it will cease to be steel" ("Comptes rendus," vol. LII., April, 1861); and the supporters of this theory go further, and affirm that steel is a union of iron with cyanogen, which can even be seen burning with a violet flame during the process of casting steel! However, up to the present time (1868), the most careful researches of Caron, Marchand, Biot, Boussingault, Rammelsberg, and others, have not confirmed the assertions of Fremy; for on the one hand, nitrogen is found also in soft wrought iron and in cast iron, and on the other, the quantity of nitrogen found in steel is very variable, and bears no fixed relation to the quantity of carbon; and furthermore, it exists in such small quantities as to be less than a tenth part of the carbon. For instance, Bussengol found 0·00057 part of nitrogen in cast steel, and 0·00124 part in soft wrought iron ("Comptes rendus," vol. LII., p. 1251). On another occasion, he found in Krupp steel 0·00022 part of nitrogen, and in soft wrought iron and in cast steel, 0·00007 each ("Comptes rendus," vol. LIII., p. 9).

With reference to the influence of different metals on the quality of steel, it is necessary to state that some of them communicate a particular colour, some diminish the tendency to rust, and others, displacing the carbon, enable the steel to acquire very great hardness in tempering, and so on; but the greater number of substances combined with steel, even in the most insignificant proportions, very considerably lower its quality.

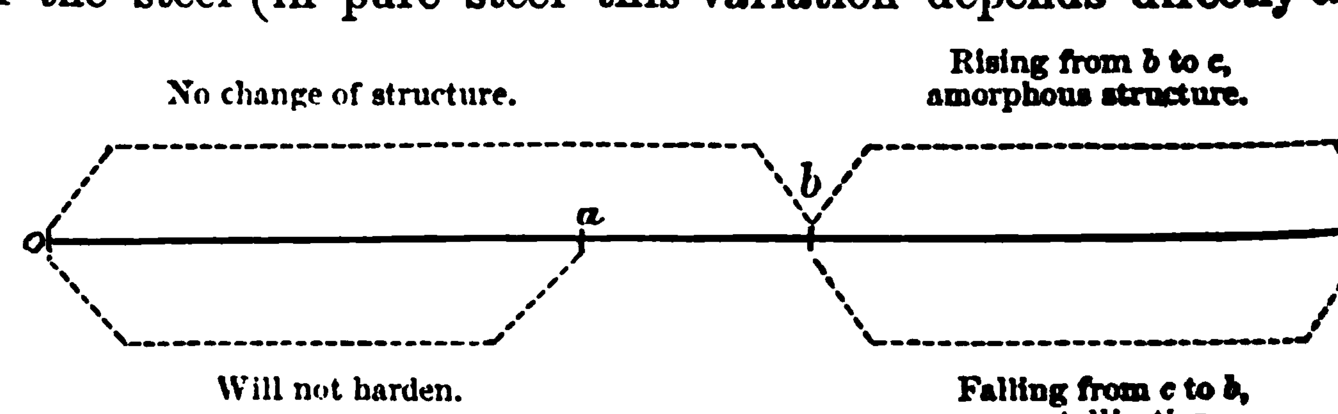
For example, the malleability of steel, being in direct relation to the quantity of carbon contained in it, is materially lowered by the presence of foreign substances. Bessemer steel No. 1, containing 2 per cent. of carbon, is hardly malleable (Boman, "Das Bessemern in Schweden," 1864); whereas, according to Anosoff, pure steel retains its malleability with 3 per cent. of carbon, forming the hardest 'boulat.' Speaking generally, all the efforts of

metallurgists to obtain the highest qualities of steel shoul
directed to separating impurities from the raw materials, so
the produce of their operations should be a combination of
and carbon; and all the specifics and nostrums forming the sub
of so-called secrets will be found to consist, in effect, not i
introduction of new materials, but in purifying the raw, and,
as a last expedient, driving out pernicious impurities by m
of substances less harmful.

It may as well be said that tungsten steel has not pro
dangerous rival to carbon steel.. The fact is that tungsten,
steel containing it is heated, gradually oxidises, at first o
surface of the ingots, and then by degrees to the very cent
that after a few heats the steel loses its peculiar qualities.
oxidation takes place even at ordinary temperatures.

As I have already stated, steel, cast and allowed to cool qu
assumes a crystalline structure. If you heat such an ingot
bright red heat, and allow it to cool without working it in
way, then, on breaking the mass, you will find that its stru
has been altered. In order to explain the law regulating
change of structure produced by heating, I draw a line, on w
as on the scale of a thermometer, I shall mark certain p
corresponding to several determined temperatures.

Let the point *o* be the zero of the thermometric scale: *a* m
the temperature of dark cherry-red; *b* red, but not sparkling;
the melting point of a given sample of steel. The points *a*, *b*
c have no permanent place on the scale, but vary with the qu
of the steel (in pure steel this variation depends directly o



quantity of carbon contained); the harder the steel the n
these points move to *o*, and the softer the steel the farther off

ing generally, with varying rates. The limits of these ments are sufficiently narrow, so that an inexperienced eye l hardly discern them. Not having suitable apparatus for ring the temperatures, I have been compelled to denote them colours exhibited in heating, the various shades of which n experienced eye can appreciate; and it must be added he colours named have reference only to hard and medium ies of steel; for in the very soft kinds, nearly approaching ought iron, the points *a* and *b* recede very far, so that, ample, in wrought iron the point *b* corresponds to white

e definition of the point *a* is as follows:—Steel, however hard y be, will not harden if heated to a temperature lower than ever quickly it is cooled; on the contrary, it will get ly softer and more easily worked with the file. Not having o enter into the explanation of this phenomenon, I will refer investigation of Jullien ("Les affinités capillaires et les nènes de la trempe mis en présence," Paris, 1866) on tempering eral: from which he deduces the very probable conclusion eel, in cooling from a red heat, appropriates a certain amount nt heat, the quantity of which is directly dependent on the cooling; so that the quicker the steel is cooled, the greater ty of latent heat it will contain; but if the rate of cooling ishes below a certain limit, then the latent heat all escapes, o hardening can take place. The actual hardening Jullien ns by the supposition that the carbon assumes an abnormal lline condition. I will add from myself that all this takes only when steel is heated above the point marked *a* on our

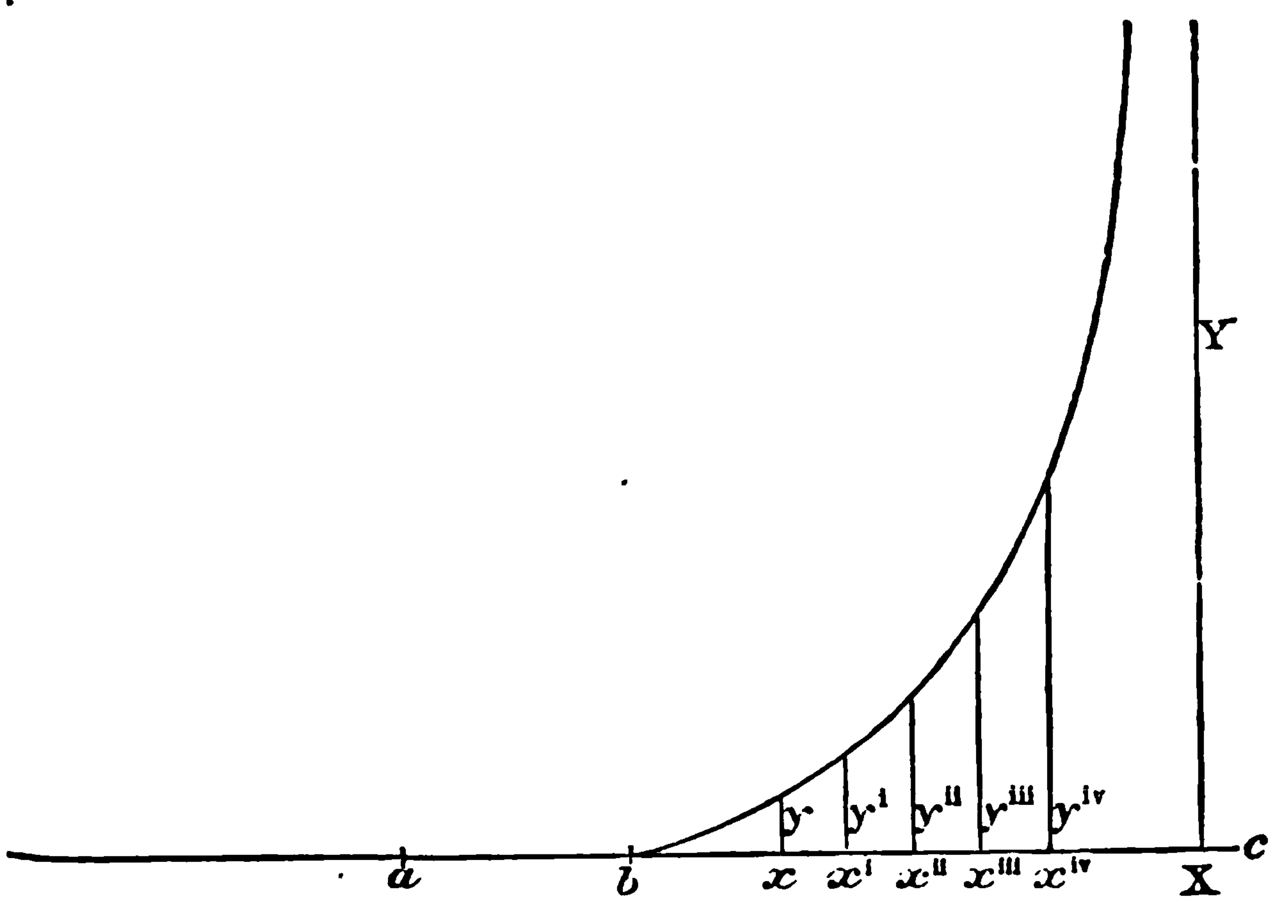
The definition of the point *b* is that steel heated to a lower erature than *b* does not change its structure, whether cooled dy or slowly. This expression however must be taken itionally, because steel, during long periods of time, and cially under the influence of shocks or vibrations, and at nary temperatures, but to a less extent than wrought iron, nges from the finely granular to the coarse crystalline icture; and as regards the heated, and therefore softened,

condition, and especially at temperatures approximating to that indicated by the point *b*, it is probable that, with the greater facility of motion, the change of structure will take place more rapidly. In my own experiments I have kept pieces of steel at temperatures near to *b* for about eight hours, but after cooling slowly in hot sand I have been unable to detect any change of structure.

As soon as the temperature has reached the point *b* the substance of steel quickly passes from the granular (or, speaking generally, crystalline) condition to the amorphous (wax-like structure), which it retains up to its melting point, that is, to the point *c*. In this condition steel possesses the property of incompressibility, and, at the same time (with respect to the permanence of the amorphism), has an analogy to an exceedingly concentrated solution of a strongly crystalline salt. To make my meaning clearer, imagine a piece of crystallised alum put into a beaker and carefully heated. On attaining a certain determined temperature the piece of alum will appear as if damp, the separate crystals forming the mass will seem, as it were, to be sticking or clinging to each other, forming a mass on the point of melting and which actually becomes gradually fluid, and forms a solution of the crystals of alum in their own water of crystallisation. Now if this fluid mass is allowed to cool it will again crystallise, and according to the conditions under which this cooling takes place we can obtain any quality of crystals, from the coarsest to grains so fine as to be scarcely perceptible to the naked eye.

If the fluid is allowed to cool very slowly, and in perfect quiet, then large regular-shaped, well-developed crystals will be formed but if, with the same gradual cooling, the liquid is kept in constant agitation (shaken up), the crystals will come out very small. Allowed to cool quietly but rapidly, the crystals will also be small; and, finally, the least favourable condition for crystallisation is when the liquid cools rapidly, and is at the same time violently agitated. In a word, all depends upon the greater or less *time* and the greater or less freedom of motion the particles possess among themselves for collection into crystals; the first condition depend

e rate of cooling, the second, upon quiet and the greater or sity (thickness) of the mass undergoing crystallisation. ame changes take place in the structure of steel heated e point *b*. The higher steel is heated, the softer it becomes; ater therefore is the liberty its particles possess to group ves into crystals (if the quiet of the mass is not disturbed neous forces); and the slower the temperature is suffered to the point *b*, the more time they have for the purpose. At tures lower than *b*, as already stated, the structure of the es not alter. In this case the action of carbon on iron may ed to that of water of crystallisation on its salt; that is, it supposed that carbon at the temperature *b* begins to iron just as the water of crystallisation at certain tures commences to dissolve the solid substance of the salt. pothesis receives confirmation in the process of cementation, h the iron must be heated to above a certain temperature fect will be produced, no matter how long the bars remain act with the carbon; it is very probable that the temperature h carbon begins to be absorbed in cementation is very near point *b*.



power of steel to become granular may be graphically ted thus:—On our scale of temperatures *o*, *a*, *b*, *c*, a curved

line rises from the point b, and the ordinates y y, &c., of this curve represent the degree of development of the grains for the corresponding temperatures x x, &c., which become the abscissæ but necessarily under similar conditions of cooling from the several temperatures x x to the temperature b. At some temperature X lower than the melting point c, the ordinate Y becomes infinite and an asymptote to the curve, the practical significance of which is apparent in the well-known fact that steel will not endure a high welding heat, but falls to pieces in the fire; and the harder the steel the lower is the temperature at which this takes place, and therefore the nearer is the temperature X to o, and the farther from c.

In manufacturing articles of steel we try to get them as much as possible of a fine-grained structure, especially if strength or toughness is the first object sought. I say that it is better to obtain steel of a finely crystalline structure, because numerous experiments have demonstrated that the greater the preponderance of the crystalline formation, and the larger and more regular the crystals in a given piece of steel, the less resistance does it offer to fracture, the less tenacity does it possess, and therefore men connected practically with the working of steel recognise its qualities by the appearance of its fracture. If the fracture is fine-grained, they say the steel is well forged and consolidated; if it is coarse-grained, it is badly forged and of an open character.

Although we are in the habit of associating with the forging of steel an idea of increased density, yet in reality it appears that, in most cases, forging changes only the form of the steel, and according to the relations between the force of the blows and the thickness of the piece of steel being worked, hinders crystallisation of the mass to a greater or less degree, but does not increase its density (I am speaking only of forging above the temperature such as is general in working large ingots). The force of the blows is too small to vanquish that gigantic molecular force of heat which keeps the particles of steel at a definite distance one from the other. The problem of forging (at temperatures higher than b) consists in this, that while changing the form of the mass of steel

it should have no time to cool and crystallise quietly, but should be kept in the amorphous condition till such time as the temperature sinks below the point *b*, after which, if left to cool in quiet, the mass will no longer crystallise, but will possess great tenacity and homogeneity of structure, so that it will oppose in all its parts a uniform resistance to external forces, of course supposing the chemical composition of the mass throughout to be the same.

But if the problem of forging was limited to the above conditions, it is easily seen that working steel under the hammer might be dispensed with, and the required form given at once by casting in suitable moulds, and preventing crystallisation by rapid cooling. In reality however things are very different. The difficulty of forging is aggravated by the circumstance that the cast ingots out of which guns, for example, have to be made are full of pores filled with gas, bubbles penetrating the interior as well as the surface of the mass, and also with scales and cracks due to contraction, so that, as the castings are delivered from the foundry, it would be impossible to make use of them. These bubbles and cracks must be squeezed or pressed together, and this can only be done by powerful mechanical means—by heavy forging. Simply unforged cast steel is neither less dense nor less strong than steel of the same molecular structure, and forged at temperatures higher than *b*. To convince myself of this, I made a number of experiments, first on the density of the two kinds of steel, and found that in most cases forging had diminished the specific gravity; and secondly, I found that the tenacity of the cast steel was in nowise less than that of the forged, provided, as I said before, both have the same structure. To prove this, I took a cast ingot of coarse crystalline structure; I had it cut longitudinally into four parts. One of these parts was turned down in the lathe, and tested in the proving machine. The second piece was heated to bright red, and vigorously forged under a 3-ton hammer, the forging being stopped when the temperature fell to very nearly the point *b*; the specimen was then turned down, and also tested in the proving machine. The third piece was made red hot, very nearly the same temperature at which the forging of the second piece

terminated, and was allowed to cool in the open air without forged. Having broken a small piece off this last speci found that it had assumed a finely granular structure very to that of the second forged specimen. The third sample w turned down in the lathe, and tested. The three specim now before you, and you may judge for yourselves what va of structure the selfsame piece of steel may be made to a The results of the experiments are given in the following ta

	Ultimate Strength, in tons per square inch.	Ultimate Extension.	Diameter of Specimen.	D Re per in U s elo
	Tons.		Inch.	In
1st. Unforged specimen . . .	34·8	0·023	0·885	
2nd. Vigorously forged specimen	41·5	0·053	0·85	
3rd. Not forged, but made finely granular by heating . .	38·7	0·166	0·63	

I must also remark, that on the fractured surface of th sample, as you may observe for yourselves, there is a spot occupying about one-sixth of the area, which was undou the cause of premature fracture, for the appearance of the clearly shows that it began at that spot.

In order to establish the propositions I have advanced, of course be necessary to institute a complete series of experim As regards trials by bending and breaking under the ha an immense number of experiments have convinced me correctness of my views.

From what has been said above, you must have perceiv the whole point lies in the structure of the steel, and t successful forging the heated ingot, after it is taken out furnace, must be forged as quickly as possible, so as to le spot untouched by the hammer, no spot in which the steel

* 1875. Since the above was written, numerous experiments at the A Works have fully demonstrated the truth of my views.

crystallise quietly, because, as I have said, the heated piece of steel must be considered in an analogous condition to a saturated solution of a strongly crystallising salt, which, the moment it is allowed to cool quietly, develops large crystals. (I repeat that this has reference to temperatures higher than *b*.)

To show how great is the tendency to crystallisation in steel heated up to a high temperature, and allowed to cool quietly even for a short time, I have brought some specimens by which you can judge of this tendency. The larger specimen was obtained under the following circumstances: an ingot of soft steel prepared for forging was allowed to remain in the furnace for half an hour after it had been heated to a bright orange heat, because the hammer was occupied by another forging. But in order not to overheat the ingot, the smith reduced the temperature of the furnace, and gradually let down that of the work to a bright red. If you will now call to mind what I have said about the tendency of steel to crystallise in cooling between the temperatures *c* and *b*, you will readily believe that during this half-hour the ingot had time to change its internal structure from the amorphous to the crystalline, a change which was greatly assisted by the extreme softening it had undergone at the higher temperature, which presented favourable conditions for the movement of the particles within the mass. As soon as the hammer was at liberty, the ingot was taken out of the furnace, and placed on the anvil; with the very first blow on its middle, the end of the ingot tumbled off from the effects of the concussion; the form of the fracture you can see on the first specimen before you. The remaining samples are taken from other ingots under similar circumstances, and they all show how strongly the crystals have developed themselves; and, moreover, each crystal seems to have formed itself in an independent manner, with so little cohesion to the neighbouring crystals that one shock was sufficient to separate them, and allow the overhanging piece to detach itself by its own weight. The specimens show that fracture has taken place only along the surfaces of the crystals, and nowhere through the body of them.

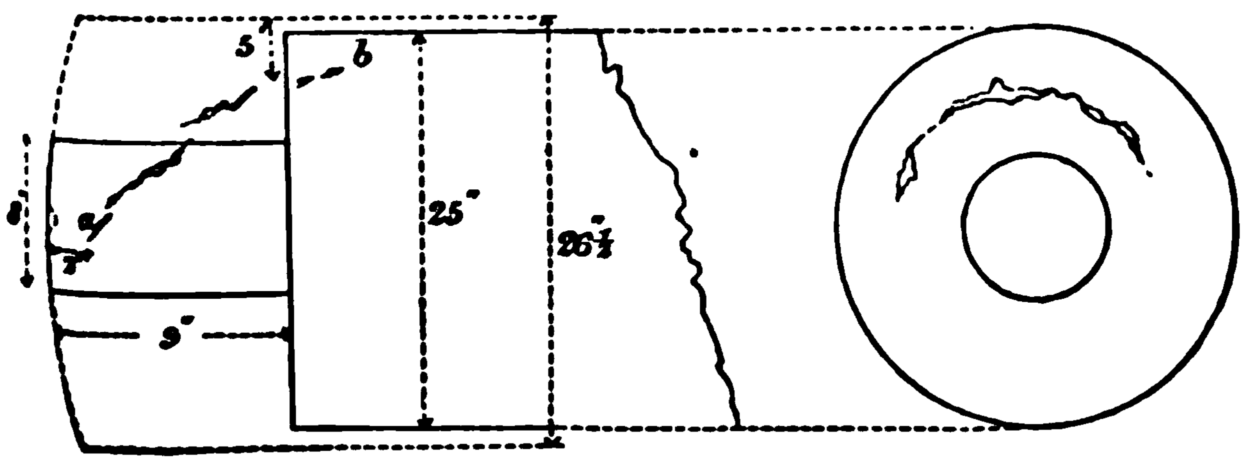
It might be concluded from the incident above described tha
the ingot was completely spoiled, and could not be forged agai
But such a conclusion would be quite erroneous. It is true tha
the higher the temperature of the steel, the more susceptible is
to the action of the furnace gases, and the quicker it changes i
chemical condition, so that if kept at a high temperature in t
furnace it will gradually lose its carbon and be slowly convert
into iron (burning). The example I have cited however is on
a case of overheating; and in order to know how to correct t
mistake made we must turn to the conditions of crystallisation.

Let us again take the beaker of melted alum. Suppose t
melting point to be t_o, and that the solution was further heated
to t_i under which operation it would continue liquid. Let t
temperature fall gradually, keeping the solution perfectly qui
then we shall find that at some temperature t between t_o and t_i t
salt will begin to crystallise; but it is only necessary to sha
up the solution to make the crystals dissolve again at the sa
temperature t. We shall notice also that there is scarcely a
cohesion between the separate crystals so formed; and if we
not wish to disturb their mutual relations, we shall have to all
the crystallising solution to cool below the temperature t_o, a
then by a second heating up to t_o we should again receive a fl
mass. The same result would be obtained by a simple sim
increase of temperature; the difference lies in this, that the liq
produced from the destruction of the incipient crystals in
three cases stated has three distinct temperatures. Applying t
reasoning to steel, it is easy to see that, in the case cited,
temperature of the ingot should have been raised again be
forging, so as to impart to it an amorphous structure; it sho
then have been quickly and unceasingly forged all over its ex
while the temperature was lowering somewhat, and the tende
to crystallisation decreasing. Or the particles that had comme
to crystallise might have been brought into a motion, correspon
to the shaking of the beaker, but very carefully, so that
crystals formed should not fall to pieces; i.e. the ingot m
have been hammered with the very lightest blows; and

temperature being higher than *b*, the crystals would have run into each other, the ingot would have assumed the amorphous condition, after which it might have been worked like a piece of wax.

It is, of course, better under such circumstances to allow the overheated ingot to cool quietly, then to heat it again, taking care not to allow the temperature to rise too high and give the mass an opportunity of again changing the restored amorphous condition to a crystallised one; the forging will then not require any special precautions, and the ingot will not tumble to pieces.

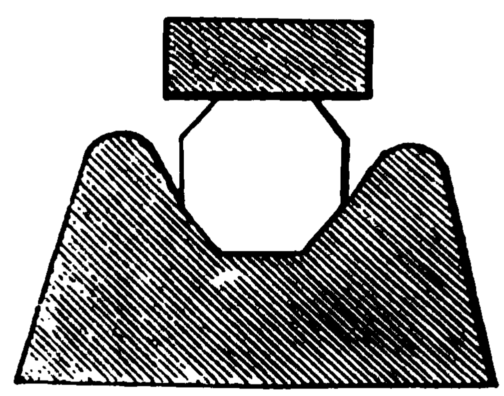
I now present you with one of many instances of the spoiling of large steel ingots from the causes I have been explaining, and proceeding from a thorough ignorance, on our part, of the material with which we are working.

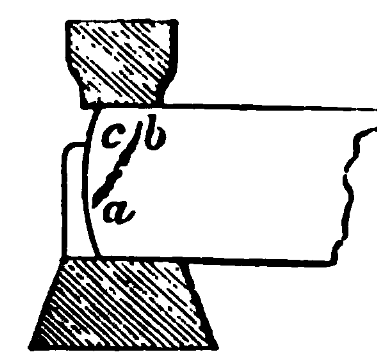


On cutting off the end of a shaft 25 inches diameter, the shake *a b* was met with in the position indicated on the sketch. The dotted lines show the form of the forging before the neck was turned. The walls of the cavity were lined with large well-developed crystals, the size of some of which—as you may see by the specimen before you—reached ½ inch, and between the large crystals were interposed smaller ones about $\frac{1}{10}$ inch diameter; the crystals projected only half their height into the cavity, and on breaking the sample at right angles to the crystalline surface, the prolongation of the crystals into the mass of steel could not be traced; the fracture, though crystalline, was of a totally different nature from that forming the surface of the cavity, and similar to that of the mass of the ingot in the same neighbourhood. The surface of the walls of the cavity had a clear unoxidised metallic

2 B 2

appearance, with a silvery lustre, as you see by the sp The ingot out of which this shaft was forged was overhe the manner I have described, and taken out of the furnac the crystals had already begun to form. At the first b the hammer on its end the part *c* which received the fu of the blow was separated from the mass on account of t of cohesion caused by the crystallisation, and formed the inclined plane *a b;* and as the forging proceeded, the oute





being more acted on by the blows, were more extended, cavity considerably increased. The fact that on striking of an ingot the force of the blow is taken up by the wedg piece *c* may be easily demonstrated to the eye, because places where swelling, compression, or tension follows t of a hammer, a dark shade is soon produced by the detachment of thin plates of scale. The same result arrived at by an analytical investigation of the effe blow on *c*.

The appearance of the crystallised surface of the specin you see, completely analogous to that of every other spe overheated steel; the difference lies only in this, that the is not oxidised, because the air could not penetrate into th while the shaft was in a heated state.

It is worthy of remark, that if a piece of steel be so overheated as to assume a strongly crystalline structi become liable to destruction at the least shock, and be al cool quietly, then the separate crystals, if they have separated by external forces while in a heated state, b joined or grown together that the fracture of the cold pie place, not along the surfaces of the separate cryst

indifferently through their mass, though the junctions of the fractures of individual crystals generally take place along their planes of adhesion, owing to which such fracture is always very sparkling.

From this it is evident that the close contact of two surfaces of metals of the same nature heated to a higher temperature than *b* is sufficient to produce union. This is, in fact, welding; and if, in welding, hammering is always necessary, it is only because, in the first place, it is very difficult without hammering to press two pieces one against the other; and secondly, that it is otherwise difficult to free the surfaces to be welded from the slag which alone protects them from oxidation during the heat. Of course the more homogeneous or analogous the structure of the two pieces, the more perfect will be the union; but one of the first conditions is that there should be the fullest contact between the unoxidised metallic surfaces.

Up to the present we have been discussing the forging of steel only at temperatures higher than the point *b*, and we have stated that the aim of the forge-master must be to change the form of his ingot in such manner as to keep all its particles in constant motion, and so hinder the formation of crystals, which materially lower the tenacity of the steel. Let us now see what circumstances arise in forging below the temperature *b*.

The fracture of a piece of cast steel presents a rough surface consisting of groups, as it were, of crystalline débris (so-called grains) piled one on another, and generally of a very irregular form. Under the microscope it is easy to see considerable interstices between the groups of grains, and, on more minute examination, spaces may be observed between the grains themselves, which form with each other various interlacings and combinations. In a word, steel, under the microscope, has a more or less porous structure, at first sight destructive of any belief in the tenacity ascribed to it. Time will not permit me to enter into details relating to the appearance, size, and arrangement of the grains; it answers my purpose simply to draw attention to the fact that among the grains of steel there are numerous vacant spaces—pores. The question

arises: what becomes of these pores when the steel, being heated up to the temperature *b*, acquires the amorphous condition? In all probability, during the rise of temperature from *o* to *b*, the expansion of each individual grain (formerly in itself a compact body) goes on incomparably faster than the increase of the externa dimensions of the piece of steel, so that the period at which i assumes the amorphous condition coincides with the moment whe the atoms composing the individual grains, moving away fro each other under the influence of heat, fill up these spaces; it i therefore conceivable why steel becomes at this stage incompressib —why it is impossible to increase its density by hammering, n matter how heavy the blows may be.

It is evident from the above reasoning that if we wish t increase the density of steel, to approach its component grains t each other and so bring them to a more energetic cohesion, w must do so when not opposed by the force of heat, that is, only a temperatures below the point *b*.

Thus, forging at temperatures below the amorphous conditio has the important advantages we are in the habit of ascribin to it. We never forge large ingots below the temperature o amorphous structure, and guns never were and never are forge below that point, because for gun steel it lies, as I have alread stated, at a dull red heat, that is, within limits below which, wit the mechanical means at our disposal, we can produce no effect o large steel masses. It would be necessary to forge small ingot under our largest hammers, and what an exhibition of inadequat mechanical appliances would be presented if a 4-pounder gun wer forged under a 35-ton hammer! The practice now is to forge th 4-pounders under the 3-ton, and sometimes the 5-ton hamme while the 35-ton hammer is used for the 6-inch, 8-inch, and 9-inc guns, in which the diameter of the cast ingot reaches up to 4 inches; but if you picture to yourself such a large mass of ste heated to a non-sparkling red heat, you will perceive that th utmost efforts of the heaviest hammer would remain inoperative— it would be impossible to forge it.

Forging is carried on at points below the amorphous condition, but it is only in very small pieces, and by those who have some knowledge of the influence of heat on steel.

If a cast ingot of any given structure is heated not higher than the point *b*, then in its heated state it will retain its structure. If it was crystalline, then in a heated state it would be composed of the same crystals, which however would be considerably softened. If the piece of steel be forged in this condition, then its crystals or grains, being driven against each other, will change their shapes, becoming elongated in one direction and contracted in another, and the increase of density becomes so considerable that I have found the specific gravity rise as high as 8, which I have never yet found in steel forged at temperatures higher than *b*. This comparatively cold forging communicates to the metal great clearness of ring, it is no longer so easily worked with the file, weak sulphuric acid produces hardly any effect on it, and so on. With regard to its absolute tensile strength, I regret very much that I have been unable to make any experiments; but there can be no doubt that it is very high.

The fracture of such steel has a silky lustre, and under the microscope it is very difficult to trace the limits of the individual grains; they present the appearance of whole groups of waxy little balls squeezed together under a powerful press. If you cut off and polish the surface of a piece of steel so treated, and then immerse it in weak sulphuric acid, after a time a pattern will form on the surface, which presents the appearance of an irregular interlacing of crooked lines, the size of the network depending on the original size of the crystals, the manner of forging, and so on. I have already stated that the tendency to crystallisation, as well as the form of the crystals and their relative positions, depends on the purity of the steel, and the conditions under which the cast ingots are poured and cooled. In the higher qualities of 'boulat,' the tracery developed by acid is of remarkable beauty and regularity.

The cause of the patterns appearing is the various groupings of the crystals during their formation. These crystals have not

by the action of acids. From what has bee
cause of this must now be quite plain, and I r
any longer.

In conclusion, I will show in what manner
cast-steel ingot may be best taken advantage o

With respect to forging at temperatures b
condition, we can only, as I have already stated
guns under the largest hammers. We have at pr
capable of dealing with large masses at low
if it were possible, there can be no doubt t
would be of the very best quality, and their
service would be facilitated by the appearan
brought out by weak acids, because of the clos
exists between the quality and the appearance o

To adapt ourselves to the means possessed
we must strive to obtain our material as much
grained structure; and with this view it is ne
already seen, to heat the ingots to a high temp
forging them until they cool down below the tem
by so doing, we shall be giving the work
and at the same time prevent its structure be
but rather make it approach the amorphous con

alter its structure to the homogeneous amorphous condition by heating it, and then fix that condition by rapid cooling to a temperature lower than *b*. For this purpose, it is of course necessary to surround the ingot after heating by some rapidly cooling medium.

From what has been said above, it is evident that, with the same rate of cooling, we shall fix the amorphous condition of the steel with the greatest certainty when we exceed the temperature *b* as little as possible; and for that reason it is well to determine that temperature for each ingot beforehand.

Having therefore heated the finished forging, or better still, the rough turned and bored gun, to a temperature somewhat higher than *b*—a point which ought to be determined by the pyrometer—let it then be plunged as quickly as possible into the cooling medium, be it water, oil, or what not; and having reduced the temperature of the work to below the point *b*, allow it to finish cooling gradually, so as to prevent, as far as possible, internal strains due to sudden and unequal contraction.

To show what changes may be produced in the structure of steel by the operations described, I lay before you three specimens. They are all broken from the same piece of steel. The first specimen exhibits the coarsely crystalline, porous structure that characterised the ingot, notwithstanding that it was well worked under the 35-ton hammer. The second sample was heated to a little above a bright red non-sparkling heat, and then allowed to cool in the open air. Comparing the fractures of these two pieces, you perceive the structure is totally different, though offering one surface to the other proves by the fit that the two pieces were at one time united, and that neither piece has been touched by the hammer since they were broken asunder. The third fragment of the same piece was heated to a bright red heat, and then quickly plunged into water, and left till the temperature sank to a reddish-brown heat; it was then taken out and allowed to cool in the open air. The fracture shows that on the external surfaces, for a depth of 0·1 inch the amorphous condition has been completely preserved. In the centre of the piece the mean diameter of the grains, as

was inadequate for the work.

A similar experiment was made with the tire of a wagon wheel. A piece of an ordinary tire was broken hammer into three pieces. One of them was heated to and then thrown on the floor to cool in the open air to th temperature. It was then put under the 5-ton ha required four heavy blows to break it, whereas the first under one blow of the same hammer. The third piece a bright red heat, plunged it quickly into water, and again when cooled to a reddish-brown heat, and then fo required five heavy blows of the 5-ton hammer to break

Therefore I say that in order to fix the amorphou and thereby to increase the tenacity of steel, it is n plunge it, after heating, into water. It may be coo but, in the first place, this is expensive, and, in numerous precautions have to be taken to prevent the fire. With respect to cooling in water, I must add conductivity of hot metal is very small, and that al external visible parts soon show the desired fall of te yet the central portions remain very much hotter; i requires care, experience, and many precautions to av rapid cooling of the outer layers, and the consequent d of severe internal strains.

It follows, from the principles laid down, that any steel article having, from constant work and concussion, lost its original strength, that is, assumed a crystalline structure, as happens to wagon axles, engine shafts, &c., can, by the help of the process above described, be completely restored by having communicated to it, if not an amorphous structure, at least one so finely grained as to be nearly equal to it, and, at the same time, a compactness and tenacity it very likely did not possess when newly taken into service.

I trust that you will now find it easy to understand the circumstances and facts which I brought under your notice at the commencement of this Paper.

I have heard with pleasure, from a friend just returned from England, that at the Woolwich Arsenal they have adopted the practice of heating their steel gun linings, after forging and rough turning, and plunging them into oil; he was unable to give me any details of the operation, as he only noticed it in passing, but the object of the treatment was, he ascertained, to give the steel greater tenacity. It is possible that I may soon obtain information as to the reasoning which led to the adoption of this practice, and I shall be exceedingly pleased if I find it is based on theories similar to those I have had the honour of laying before you this day. With respect to the doctrines I have been advocating, I have been accused of being too bold in my conclusions; but I am prepared to take a still more decisive step, and to announce the opinion, resulting from my observations, that "future investigation into the question of forging steel will not deviate from the path into which we have this day directed it."

Institution of Mechanical Engineers.

PROCEEDINGS.

August 1880.

The Summer Meeting of the Institution was held at Barrow-in-Furness, commencing Tuesday, 3rd August, at 10 a.m. The President, Edward A. Cowper, Esq., and the Members of the Institution were received in the Town Hall by the Mayor of Barrow, Edward Wadham, Esq.

The Mayor, in the name of the authorities of Barrow, begged very heartily to welcome the Institution of Mechanical Engineers to the town of Barrow. He trusted the Members of the Institution would see some things that would interest them; and felt quite certain that the inhabitants of Barrow would themselves derive great benefit from the information which they would gain by the papers to be read, and from the opportunity afforded them of associating with so many men of learning and science.

The President, on behalf of the Institution, wished to acknowledge the kindness of the authorities of the town, in giving the present invitation, which had been accepted with very great pleasure by the Council of the Institution. The members present would have the opportunity of seeing the numerous manufacturing operations which were carried on at Barrow, and he had no doubt that the visit would be to the mutual advantage and pleasure of all.

The Chair was then taken by the President, Edward A. Cowper, Esq.

The Minutes of the last Meeting were read, approved, and signed.

The PRESIDENT announced that the Ballot Lists had been ope by a Committee of Council, and that the following New Memb Associate, and Graduates, were found to be duly elected :—

MEMBERS.

WILLIAM HENRY BELL,	Liverpool.
WILLIAM BOW,	Paisley.
DANIEL CAMPBELL,	London.
GEORGE DUNDAS CHURCHWARD,	Dover.
CHARLES EDWARD COWPER,	London.
JOHN DODD,	Oldham.
FREDERIC ELIOT DUCKHAM,	London.
SAMUEL GEOGHEGAN,	Dublin.
CHARLES GILL,	Java.
ALEXANDRE GOTTSCHALK,	Paris.
JAMES GRESHAM,	Manchester.
JAMES HORNSBY,	Grantham.
WILLIAM HORNSBY,	Grantham.
EMIL KESSLER,	Esslingen.
MICHAEL LONGRIDGE,	Manchester.
JOHN MCLACHLAN,	Paisley.
ROBERT AUGUSTUS OLDHAM,	London.
THOMAS ORMISTON,	London.
THOMAS ROUTLEDGE,	Sunderland.
RICHARD SCHRAM,	London.
GEORGE STAFFORD,	Nottingham.
WILLIAM HENRY THORNBERY, JUN.,	Birmingham.
WILLIAM ANDREW MCINTOSH VALON,	Ramsgate.

ASSOCIATE.

DAVID HENRY HAGGIE,	Sunderland.

GRADUATES.

HERBERT BIRKETT,	Dartford.
THOMAS SMITH BRIGHT,	Carmarthen.
WALTER SAUNDERS PATERSON,	London.

PRESIDENT had great pleasure in announcing several Donations to the Library, and hoped that there would creased interest felt in making this a really valuable library nce. It was rapidly becoming so, and with the help of the f the Institution he believed it would be of great value to bers. It contained some important works which were very nd difficult to obtain; and a number of good scientific rere being gradually accumulated. The first of these s was one of Ten Guineas from the Auditor, Mr. R. A.

The second donation had been presented by Messrs. Brothers, the owners of the Institution offices in Victoria 'estminster, and consisted of a nearly complete set of the ngs of the Institution of Civil Engineers. The third was nal parliamentary plan of the Liverpool and Manchester given by Mr. G. B. Rennie. He was sure the members el that their thanks were due to these gentlemen, and to all added to the value of the library.

PRESIDENT said there was one other matter to which he had It was of a somewhat painful character, and he was sorry o notice it, but the Council decided that it could not be rer. One gentleman, not a member of the Institution, had o add to his name "M. I. M. E," which of course meant r of the Institution of Mechanical Engineers," though the did not habitually use those initials. His name was P. Burgh. He had been written to on the subject, and he d that the letters did not mean "Member of the Institution nical Engineers," but "Member of the Institution of Marine s." He (the President) believed there was a small society ame.

PRESIDENT then read his Address as follows:—

ADDRESS OF THE PRESIDENT.

GENTLEMEN—I do not propose on the present occasion to
you with any long history of the progress of Mechanical Engin
as you have had at previous meetings more or less complete
of such progress, and particularly as various matters press the
very urgently on our notice at the present time, and dem
appears to me, very serious reflection on our part. I allude of
firstly to the very great and general depression in trade th
now held its dull course for years; and secondly to the me
our power that are, or are not, being taken advantage of, to p
the manufactures and commerce of the country.

Now, I am not one of those who would, for a single moment
of sitting quietly with one's hands before one, and sayin
" foreigners choose to do the work which we have been in th
" of doing exclusively for many years, and thus take away our
" we cannot help it, as we cannot prevent them from becoming
" educated in manufacturing arts than they were."

But let us examine the situation frankly and fully, and
reasons of the changes that have undoubtedly taken place;
shall find that one of the primary causes consists in th
(which I ventured to allude to on a previous occasion) that
the thirty years' war on the Continent very little att
comparatively speaking, was given to manufacture, becau
populations were much engaged in preparing for fighting,
actual warfare, and in tilling the ground for a bare subsistence
before considering the present era, let us glance (and glance

at the fact, that in bygone times it was much the fashion, if some ingenious engineer were required for a special work, such, for instance, as making a dock, or a bridge, draining fens, or other public works, to call in a Dutchman, or an Italian, or other foreigner; so that we must not say that in those days England always produced just the men that were wanted, though for a very long period now, I am thankful to say, the first engineers in the world have been produced in this country.

I merely mention this fact at starting, in order forcibly to keep in view the changes that can and do take place in the supply of the talent necessary for public works, and for the vigorous prosecution of the manufactures and commerce of a country.

I think it is advantageous and wholesome for us sometimes to look around, and to examine and reflect on what has made this country the manufacturing and successful country that it is, and what is now wanting to enable us to continue to hold that proud position securely.

I am well aware that some thinking men consider that technical education, such as is given in Germany, is what is wanting in this country; and, although I think much more than this is needful, I give all honour to the earnest men who are striving to promote technical education in London, and in all the large cities and towns of England. I need hardly mention the name of Mr. Bramwell, your Past-President, and the leading men in some of the richest City guilds, as amongst the most forward in this good work; there being now about £12,000 a year spent in this cause, besides large sums that have been given to inaugurate the schools.

But, at the risk of my being said to repeat a matter that I mentioned when I had the honour of taking this chair, I do most emphatically call the attention of manufacturers generally throughout the country (not of mechanical engineers only) to the advantages that they would reap, if they generally and systematically threw more enterprise into their business, and showed greater interest in investigating and adopting new improvements in manufactures.

I will attempt to illustrate my meaning, and to cite a few examples of real enterprise, and the immense effects they have had

on the manufacture, the commerce, and the very position of country amongst nations.

Take for instance the new manufacture which has made important town, and is its chief industry, (and is, in fact, cause of our being assembled here to-day). I allude of cou the Bessemer manufacture; and one reason why I call it Bessemer manufacture" is, that we owe to its author not the invention, but also the introduction of the steel, when made the market. For it is well known that manufacturers had n enterprise to take up the invention and prosecute it to a p success, until Sir Henry, then Mr. Bessemer, and certain capit had spirit enough to go into the business; when, with the f assistance of Mr. Mushet's manganese, it was soon an accompl fact, that good steel could be made in immense quantities at altogether unheard of before. Here we see gentlemen, altog outside the trade, giving the country an essentially good and providing work for thousands of our artisans. The introd of the Siemens process, for very mild steel, also deserves es notice, and the steel is in great demand. I believe it is to efforts as these, and to such enterprise as we shall see dev here at the Steel Works, the Shipbuilding Works, the Dock Jute Works, &c., that we may look for the retaining and incr of our trade and commerce.

If not wearying you too much, I should wish to allude to other inventions and enterprises, which, as every thinking man admit, have had a like effect on manufactures and commerce I must at the same time, and in common justice, mention cases in which the British manufacturer has, I am sorry t been lamentably behind in the race of improvement. I h my lifetime seen the whole of the railways in the kingdom construction, with the exception of the Stockton and Darlingto the Liverpool and Manchester, and the latter I went down the first year after its construction; so that I have taken of a very large number of what are commonly called "m improvements"; and I may perhaps also name a few of those were young when I was a lad.

There is no doubt but that we are largely indebted to our rich natural resources in mineral wealth, such as coal, clay, lime, salt, stone, iron, lead, copper, tin, &c. &c., whilst another very important factor is the natural wit and industry of the English character, which is so different in many respects from the lethargic, versatile, or idle character of some other nations; and I argue that, in view of these facts, it would indeed have been a shame, if many good, new, and useful results had not been produced, though I maintain that many more might have been generated, had more enterprise and less conservatism in old ways been shown.

One of the earliest and most marked improvements, in the conveyance of merchandise of all kinds inland, was the large development of canals by Brindley, at once reducing the cost per mile from about 10*d.* to 1*d.*; so that the materials produced in one part of the country were able to be transferred to other parts, where it was possible to utilise them; and merchandise could also be conveyed to large towns or ports for shipment. This improvement tended largely to develop the resources of the country, and greatly to assist those who were principally dependent upon agriculture. The successful exertions of Smeaton, in improving water-wheels and windmills, did much to supply the country with power for grinding and pumping, as well as for forge and tilt hammers, and for blowing engines in iron-works; but the amount of water-power available in the country is comparatively small, far too small to meet the necessities of manufacturers. The next vast step in improvement was undoubtedly the introduction of the steam-engine, first by Newcomen simply for pumping, and secondly by Watt for general purposes, thereby immensely stimulating the old manufactures of the country, and giving rise to many new ones. The case of Watt is one which clearly shows the advantage of the patent laws in stimulating invention, by enabling the inventor to reap a portion of the advantage of his own discovery; for it was distinctly the fact of his having a patent that caused his moneyed partner, Boulton, to persevere in bringing the invention to bear on an extensive scale. And here, in passing, I may call attention to the fact, that fourteen years was not enough to develop the most

useful invention of our times, and that another fourteen years w given. The service rendered also by Trevithick, in the introducti of the high-pressure steam-engine, was much more important than generally acknowledged: it certainly is not universally known t he ran a locomotive engine on a circular railway, about 1804, in Eust Square, (I may mention that my own father saw it running the inside an inclosure, and it ran round so fast as eventually to le the rails).

The progress of improvement in manufactures, after the inventi of Watt was brought to bear, was much more rapid. Cotton-spinni was quickly improved; Arkwright introduced his spinning-fran Crompton introduced his mule, and Roberts his self-acting mu and finally Cartwright introduced, the power-loom. The manufact of soda from common salt was introduced, and was a most valua invention. The paper-making machine was invented: bleachi and dying were much improved. The printing-machine w brought to bear, and at once spread knowledge at the rate of 1,2 large sheets per hour, printed on both sides, in place of small shee only printed on one side, at 250 per hour: I trust you will exc my mentioning this in honour of my late good father. A little la the Jacquard or figuring loom was brought forward; steam navigati and later on ocean steamers, became a complete success; and pott and porcelain were much improved in various ways.

Then came the grand strides made by railways, and the consequ cheap and quick conveyance of passengers and materials in directions, thus enabling numbers of industries to be establish and worked with advantage, and giving employment to tens thousands. In shipping it only required experience of the ent success of the first iron ships, the *Garry Owen* and *Aa Manby*, to give iron ships a firm footing, though the advocates wooden ships delayed their introduction for a time. At the prese time, the immense advantages obtained by the introduction of mi steel in ship-building are increasing the ship-building trade of t country in a remarkable degree: examples of this we shall see, hope, this afternoon, together with the great improvement of doubl plating the bottom, up to above the bilge.

eat economy with which steam-ships can now fetch and rals of low value, in enormous quantities, throughout the bined with the immense facilities afforded by railways, iost any kind of material to be transferred from any n the globe, where it may be produced, to any other e it may most economically be utilised, and where real its in manufactures may be made. Great effects may duced. As an example, some of the most sulphurous of South America, which formerly were not worth the this country, are now used in immense quantities, owing ition of an improved furnace for roasting them. I allude mhofer furnace, in which the burning of the sulphur from red ore accomplishes its calcination. The sulphurous s produced is used to make sulphuric acid, and the acid o make soda out of common salt. I merely mention e instance among hundreds in which several different es have been improved at the same time by one simple

phs then came to our aid, to facilitate the interchange of , and particularly did ocean telegraphs help greatly important communications between continents. I must well upon the immense variety of telegraph instruments nces, whether acting by codes, read by the eye or by writing by hand, or recording by a line; but the great accomplished by duplex and quadruplex signalling, e wire in both directions, has been a marked improvement age, and contrasts strongly with Professor Wheatstone's ır wires, with the rails of the railway (as was supposed) wire.

on to the most recent improvements, we shall, I trust, see (and for the first time in England) liquid steel, in ds, submitted to the pressure of high-pressure steam, in npress the bubbles of gas in the mass, and so render the sound; on the same principle as is employed by Sir Joseph when he uses hydraulic pressure. Another very interesting e, which we shall have full opportunity of seeing, is the

Jute manufacture, which has risen to such large proportions, t
some manufacturers have moved their establishments to India, wh
the jute is grown, and where labour is very cheap; whilst the rec
use of the stump, or lower part of the jute stalk, for paper maki
has gone some way to reduce cost. Wire-rolling mills are also to
seen in the neighbourhood, where lengths of a quarter or even hal
mile can be rolled out from one billet ready for being dra
There is likewise a Hoffman kiln for burning bricks in the m
economical manner, by utilizing the heat of bricks that h
been burnt for heating up bricks to be burnt. The large doc
with immense concrete retaining walls, and their large gates
other appliances, will be found well worthy of attention; and Mr. Jo
new slide-motion will demand careful consideration, particularly
reference to its application to locomotives, an excellent specim
of which has been brought here by Mr. Webb, with the mot
applied in his own way, and with the last improvement in a sli
valve, which gives a double-quick opening at the beginning of
admission.

I find my time running short, and therefore must not dwell
other improvements in machines and manufactures which h
certainly helped the commerce of this country, such as in
preservation of food, stereotype printing, the preparation of inc
rubber, fog-signals, gas manufacture, photography, weaving, plat
metals, machine tools, candle-making, lace-making, tea-rolli
machinery for lifting weights, hydraulic machinery, interlock
railway signals and points, railway brakes, writing instrume
sugar machinery both for cane and beet, bolts and nuts, scre
locks, anchors, steam-hammers, lead and iron pipes, blast furna
gun cotton, dynamite, nitro-glycerine, steel masts and yards, steer
apparatus, economical engines, microscopes, telescopes, spectrosco
thermometers for discovering icebergs at sea, artificial leat
agricultural implements, sinking piles by means of a jet of wa
fire-engines, &c.; and I may perhaps add to these Sir He
Bessemer's very ingenious idea of a high-temperature furnace, w
gases under pressure, and Dr. Siemens' elegant experiment of melt
steel in a crucible with the electric current generated by a dyna

magnetic machine driven by an engine, and his plan of stimulating the growth of plants, by making them grow night and day by electric light.

Perhaps you will be inclined to ask me, why I have thus conjured up to your mind's eye a number of inventions and improvements which you know have helped to make England's greatness: for this reason, that I want manufacturers to appreciate much more than they do at present, that *such vast improvements having been made, further important steps can be taken*, so as to keep England always in advance of all other nations in Manufactures and the Arts, if only more enterprise and energy are shown in taking up known good things, in inventing new processes, and prosecuting them to success.

For instance, sewing machines ought to be made here, and I urged English makers, years since, to go in thoroughly for making every part accurately and by machinery, so as to fit together at once without "fitting;" but I could not get this carried out, and now sewing machines come from America literally by millions, though labour is dearer, metal is dearer, and there are upwards of 3000 miles of carriage against them. But "*machine manufacture*" is cheaper and better than "*hand-making*."

In gun-making I counselled some of the Birmingham makers, years before they did anything in the matter, that they would actually lose their trade if they did not adopt good machinery to manufacture every part exact to size; and at last, when the Government had the means of doing most of the work, they did adopt machinery, but many years too late.

Then with regard to common pumps, they are now imported from America by thousands, and are sold here, without being commonly known to be American; clocks and watches also come in immense numbers, some of them very cheap and common, whilst others are very well made. Another trade, nearer perhaps to most of us, is that of rolled iron girders, which I am sorry to say are coming by hundreds and thousands from Belgium; indeed almost every house that is now built in London with rolled iron girders is supplied from Belgium. These things should not be: we have iron in plenty, and labour in abundance, but we want *special machines*, schemed as fast as they are

wanted, to fit the work properly, and turn it out accurately in large quantities; and we should show more enterprise in adopting a good "new thing," which I am sorry to say is what some of our old-fashioned manufacturers are slow to do, often little knowing how they damage the trade they are in by not adopting the best known process.

Finally I venture to think, that one of the best results of our Institution meeting in various localities, from time to time, as we do to-day, is that there is free intercourse between those who are in one line of engineering and those who are in another line; and that such comparing of notes and observations as naturally takes place in conversation is most conducive to the obliteration of prejudices and wrong notions, and particularly to the removal of the illusion, that what is now being done cannot be improved.

This great advantage of meeting and interchanging ideas was fully contemplated by those who assisted in starting this Institution, and it is most gratifying to think that it has, on reaching maturity attained the position it now holds in the mechanical engineering of the world. I trust sincerely that the Institution will go on and prosper for many a long year after we have all departed and are forgotten, and that it will aid materially in advancing the manufactures and commerce of this country. I can only urge further upon every Member, Associate, and Graduate to strive in every way to promote the usefulness of the Institution.

MR. EDWARD WILLIAMS desired to propose a vote of thanks to the President for the able address to which they had just listened. They had been reminded in a very candid way of their short-comings, and he had no doubt they would all agree that they very often did come short of what might be expected of them. He (Mr. Williams) was not one of those who believed that they were lamentably

behind their foreign friends, or that foreigners were taking from them business which used to belong to this country, and which it might legitimately expect to hold. His view of the case was rather that the world required very much more than this little island, were it ever so active or skilled, could possibly supply. Speaking for the manufacturers of iron and steel, he did not think it could be fairly said that they had fallen behind foreigners during the last few years. The Bessemer process had been taken up very early in this country, and not altogether by outsiders to the trade, as stated by the President. Within a very short time of the announcement of the discovery by Mr. Bessemer, it had been taken up at Dowlais, and carried out very ably and vigorously by Mr. Menelaus. Girders also were made at Dowlais as well as they were ever made abroad, on a much larger scale, and at a lower price; but the business proved unremunerative. It so happened that it suited the Belgians to do that special branch of trade, and they were actually nearer London than most of the English manufacturers. He was not finding fault with anything that had fallen from the President; but he desired to say a few words in behalf of the manufacturers of this country, who he hoped and believed were not so lamentably behind as was sometimes made to appear. Steadily the volume of their business increased, as he believed it would continue to increase; and knowing as he did the character of their workmen, he had no fear of being left behind, either in the discovery of new processes, or in the carrying out of the proccsses that had been discovered already.

As iron-workers they were not well off in the matter of mechanical appliances; and they ought long ago to have got into the habit of doing by machinery that which they had done year after year, and were still doing, by manual labour. The blame for that state of things rested with the mechanical engineer, and not with the iron-worker, who wanted more mechanical aid. Speaking therefore not as a mechanical engineer, but as an iron and steel maker, he had to complain to the gentlemen present that they had rather lagged behind the requirements of their business; and he hoped they would take the advice of the President, mend their ways, and

provide the assistance wanted by makers of iron and steel. I begged to propose that the best thanks of the Institution be giv to the President for his address, and trusted he would allow it be printed in the Proceedings of the Institution.

Mr. JOHN ROBINSON said he had much pleasure in seconding t motion. The speech of Mr. Williams, contrasted with the addr of the President, illustrated one of the advantages which t President had pointed out in such meetings as the present, name that of bringing together men of different classes of mind. He h not quite understood from Mr. Williams the reason why the Dowl works had given up the manufacture of girders, which, as t President had stated, were now made in such large quantities Belgium for building houses in London and elsewhere. As Englishman he did not like to think that pig-iron produced in th country should be carried across to Belgium, and then brought ba in the shape of girders.

With reference to the President's address, he thought they a owed him a debt of gratitude for recalling to them what they we too often liable to forget, namely the great progress which t country had made in manufacturing and engineering. In times li those through which they had recently passed, he was quite su they required all the encouragement possible, to stimulate the in making further progress, instead of sitting down and sayin "We cannot go any further ourselves, but must leave other natio to take up the race where we have left off." He hoped that wou never be said of England; and that if some of them were too old make progress, those who were younger would rise up and follow the good path indicated by the President in his valuable addre He had great pleasure in seconding the vote of thanks proposed I Mr. Williams.

Mr. W. MENELAUS said it had been asked why the manufacture girders at Dowlais had been given up. They had commenced th manufacture very early: happening to be in Paris he had se large numbers of such girders being used. As trade was not ve

.e built a mill for the purpose of rolling those girders; ey went into the trade, English architects would not s, as he expected they would do, in their buildings, so as positively little or no demand for them. They had tons or 12 tons at a time; some wagon-builders had uch as 50 tons; but the trade would not answer. They ers cheap enough, but there was little or no demand for and that being so, and the steel trade coming in, he had e machinery for rolling steel; abandoning the girder Belgians, who he hoped had found it profitable. It had t Dowlais as far as it went, and, if they had been by English architects, they would have been rolling e present day; but, after persevering for years, they had eir machinery into something for which there really was nd he thought they were fully justified in the course pted.

hen Mr. Bessemer introduced his process to their notice, erfected it; and though they carried out his instructions t was not a success. Mr. Bessemer then went away and y worked his process out in another part of the country; s he had perfected his process, they were ready to start, l gone on ever since with a fair amount of success and

of thanks was put to the meeting, and carried by

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lowing paper was then read:—

ON THE DOCKS AND RAILWAY APPROACH AT BARROW-IN-FURNESS.

By Mr. F. C. STILEMAN, of London.

The title of this paper was adopted from a suggestion Secretary, with the omission of one word—the epithet "new reason for this omission being that the whole of the Town, and Railway at Barrow-in-Furness are new, the Act of Parl incorporating the Furness Railway having been passed in 18 Dock Act in 1863, and the Town having been incorporated in The Author has had the privilege of being professionally co with most of the engineering works of the town, and of watch rise and progress from the time of its foundation. As a pupil late Mr. J. R. McClean, he was instructed to find his way to B the means of doing so not being recorded in Bradshaw, and to the railway between Barrow and Piel to Dalton and Kirkby. contract for this portion of the railway was taken by Messr and William Tredwell in 1844. The line was opened in June for the carriage of iron ore and slate, which was shipped from a T headed wooden pier erected by the Railway Company at Rabb Point, about the site of the present Barrow station. At this ti mineral owners would not undertake to guarantee the Railway Co a traffic of 75,000 tons of iron ore per annum; but soon af opening of the line a great development of the iron ore traff place, and this quantity was increased fourfold. By degre railway system has been developed, and various other lines been absorbed, now forming together the Furness Railways, run from Lancaster, *viâ* Carnforth, to Barrow and White and combine business with pleasure traffic, the latter to Wind and Coniston lakes. The requirements of this district now d

quick communication with London, Liverpool, Manchester, and Leeds, which is supplied by the express through trains of the London & North Western and the Midland Railway.

In Fig. 1, Plate 33, is shown a general plan of the railway approaches, docks, and sea highway; and Fig. 2, Plate 34, is a larger plan of the docks, together with the chief features of the town of Barrow.

The first harbour authorities (the Barrow Harbour Commissioners) were constituted under the Act of 1848. The powers therein granted becoming inadequate to the rising port, the Commissioners' authority was enlarged in 1855, and became vested in the Furness Railway Company in 1863; and by the same Act power was also given to construct docks. The construction of the docks then authorised, situate between Barrow and Barrow Island, was let in 1865 to Messrs. Brassey and Field. The docks have been named after the two Dukes, Devonshire and Buccleuch, the chairman and deputy-chairman of the Furness Railway; and were formally opened on the 19 September 1867 with great public enthusiasm.

The Devonshire and Buccleuch docks have together a water area of 65 acres. Their length is 5500 feet, and width 500 feet, with a depth of 24 feet. They are entered through a basin 500 feet in length by 150 feet in width, worked by a pair of double-skinned wrought-iron gates, 60 feet wide in the clear, and by a wrought-iron caisson. Adjoining and parallel with the basin is a graving dock, capable of taking a vessel of 5500 tons burthen.

The north side of the Devonshire dock was allocated to traffic in grain, jute, &c., and the shipment of steel rails and hæmatite pig iron; the principal portion of the south side being reserved for, and now used by, the Barrow Shipbuilding Company and the timber trade: whilst the Buccleuch dock was more particularly reserved for the shipment of iron ore and timber, a trade generally carried on in a smaller class of vessels. Under these circumstances the entrance between the two docks was made 40 feet wide, or 20 feet less in width than the entrance into the basin.

In 1872 the railway company obtained an Act authorising an extension of their docks, which was completed and opened in May of

last year. This extension, called the Ramsden dock, ha
named after the managing director of the Furness Railway;
Author trusts it will be a lasting tribute to the energy
James Ramsden. The access to this dock affords a seco
into the entire system of docks; it is through a basin 900
length by 250 feet in width, having an area of 8 acres, int
700 feet long by 100 feet wide, and nearly 2 acres in ar
thence into the Ramsden dock and basin of 56 acres of wa
Besides this a further area of 200 acres has been enclosed
Cavendish dock and quays. The minimum width of the
to these docks is 100 feet. The outer cills are placed
lower than those of the Devonshire basin; while those at th
end of the lock, or second entrance to the docks, are at th
level with the cills of the Devonshire basin.

The masonry of the basins, lock, and docks is built
sandstone, chiefly obtained from Hawcoat quarry, 1½ mile
In the construction of the basin and quay walls a large am
concrete has been used in various proportions, the most usu
1 part of hydraulic mortar made from Aberthaw pebbles, and
of gravel or shingle, taken from the southern end of Walney
In Figs. 3 to 5, Plate 35, are shown sections of these walls.
work, the excavation for the foundations, where trenched, was r
by buckets and skips, and the concrete was put in position
same means. Concrete was also passed down through te
wrought-iron tubes; but it was found that the cement floate
top of the tube, and this plan was ultimately abandoned in fa
the skips.

The invert of the lock is built of blue Flintshire bricks; t
hollow quoins, and copings of Cornish granite. The slopes
outer embankments, reclaiming the land for the site of the do
at 2 to 1, and are pitched with 12-in. sandstone pitching
12 in. of clay puddle, the interstices being filled with broke
This mode has also been adopted for some of the inner slop
trade requires it, jetties will be built out to the foot of th
slope for vessels to lie alongside. The foundations prov
variable; some of the walls, especially a great part of th

channel wall, are erected on piles and flooring, as shown in Fig. 3, Plate 35; other portions have piles driven as a sheeting in front of the masonry. Amongst other means used for excavating the dock, the steam navvy was successfully employed; its employment in stiff clay and gravel is very economical, saving much cost in getting. The work done by a 10 horse-power "navvy" per day was 600 to 800 cubic yards filled into wagons.

The basin and dock gates are of wrought iron, segmental in form, and struck to a radius of 75 ft. 6 in., with a versed sine of 21 ft. The sea gates are plated to a greater height than the others, so as to exclude the equinoctial tides from the docks. Each leaf of these gates is 57 feet in length, measured on the arc. The framing consists of H-shaped built ribs, placed horizontally at various heights according to the water-pressure they have to sustain, and connected at five points by vertical frames, similar in shape to the ribs. At the back of each alternate rib is fixed a horizontal lattice frame, tied and braced vertically at the five upright frames. At the back of the gate, and attached to the framing at every point of intersection, are two diagonal bars, supporting and bracing together all the framing of the gate. The main ribs are plated on the outside up to the water level of the dock. The heel and mitre posts and the clapping cills are of greenheart timber. The centre of the heel post is set slightly eccentric with the centre to which the hollow quoin is worked; so that in opening the gate the heel post is at once freed from the masonry. The pivot, and the top and bottom shoes of the heel posts, are of cast steel. The gate is anchored back to the masonry by a wrought-iron strap, passing through a massive cast-iron anchor plate, which is built into the masonry and secured by long wrought-iron ties. Each gate is provided with one cast-steel roller, 2 ft. 6 in. diameter, placed 47 ft. 6 in. from the heel post, and carried by a vertical shaft having adjusting keys at the top. The weight of one sea gate, 57 ft. long and 36 ft. high, is 107 tons; and the gross weight, including the pivot, anchor plate, straps, roller-path, &c., is 127 tons. Each gate is provided with a single chain attachment for opening and closing, and with four sluices acting in pairs. There is a gangway

at the top, and that across one pair of gates is made sufficiently wide for vehicles.

The railway and road approaches across the docks are as follows, as shown in the plan, Fig. 2, Plate 34:—

1st. The north road, crossing the inner end of the Devonshire basin by a lifting and rolling bridge, 60 ft. clear span and 13 ft. wide.

2nd. The middle road between the Devonshire and Buccleuch docks, for vehicles only, formerly passing over a 40-ft. swing-bridge, in two leaves worked by hand-power. This entrance is now being widened to 80 ft., and the bridge is proposed to be a rolling one at a higher level.

3rd. The Buccleuch dock bridge between the Buccleuch and Ramsden docks, crossing an opening of 80 ft., in two leaves. It is separated for railway traffic, vehicles, and foot-passengers, and has an aggregate width of 31 ft. The general construction of this bridge is shown in Figs. 6 to 13, Plates 36 to 38. The gross weight of each leaf is 116 tons, carried on a pivot P, by means of a pair of spring girders G G. This arrangement relieves the dead weight of the bridge off the bearings B, Fig. 10, which are in advance of the pivot; whilst the spring girders yield sufficiently to allow of the bridge taking all its bearings under a passing load. The two leaves are connected in closing by a groove and key, Fig. 9, having a slight draw, which maintains the ends of the leaves in level and direction.

An 80-ft. fixed bridge is provided across the opening from the Ramsden into the Cavendish dock (at present to be used as a timber pond), for the road to the cattle lairs, slaughter-house, and chill room on the Foreign Animals wharf.

Nearly all the machinery for working the gates, sluices, capstan cranes, pumps, bridges, grain elevators and bands, &c., is worked hydraulic power, transmitted from two stations; one near Devonshire dock entrance, the second near the Ramsden dock entrance Fig. 2, Plate 34. An intermediate accumulator is fixed near the 100-t crane of the Devonshire dock. Nearly all the hydraulic machine and plant has been provided and erected by Sir William Armstro and Co. The 100-ton crane was also arranged to lift 7-ton load working over the same roller path; this has not been found to be

mical arrangement, since the whole dead weight of the crane o travel over the roller path whether for the greater or lesser

rrow harbour is protected for its whole area by the Isle of ey, which is about 10 miles in length, as seen in Fig. 1, 33. The chief entrance is at Piel, at the southern end, the rise of tide is 28 feet at springs, and 21 feet at equinoctial tides rising to 33 feet. The Furness Railway any for the last ten years have carried on extensive dredging tions, employing four steam-dredgers, steam-barges, and ons, in straightening and deepening the channel between Piel e Devonshire dock entrance. The result is shown in Fig. 1, 33, where the strong dotted lines mark the new channel. A t the entrance to Piel is now being removed to a depth of et below low-water of ordinary spring tides; and this work, completed, will enable vessels of the largest class to enter early ollow up the tide to the docks.

Discussion.

r. T. Ormiston had long heard of the Barrow Docks as very ive and successful, and as another proof of the great energy some of the nobility had thrown into the extension of public in the country. He hoped therefore it would not be lered that in what he was about to say he was criticising the in an unfavourable spirit, and he spoke under the disadvantage having yet been over the works; all that he desired was to elicit nation and provoke discussion. One thing that he should like ow was why the graving dock at the Devonshire entrance had placed outside; because in a general way it was considered that reat advantage of having a graving dock in connection with a lock was that repairs to ships could be made without going le of the wet dock.

'It appeared to him that the deep entrance to the Ramsden basin was excellent, but that the raising of the inner lock cill 6 ft., or to the same level as the Devonshire cill, had prevented the full use of the large area of docks inside; and he should be glad of further information on that question.

Another question he should like to ask was why the entrance had been made so wide. Since paddle-steamers had been given up for the sea-going trade, it was generally held that nothing like the width of 100 ft. was required. He did not know any steamer afloat of anything like that width, except perhaps the *Great Eastern;* and it was not worth while to make exceptional arrangements for one ship. There was no ship that he knew of having more than 52 ft. beam over all. In a dock which he had lately finished he had designed the width to be 60 ft.; but he was overruled, and it was made 66 ft., which he thought was wider than necessary. At Liverpool he believed the standard width of entrance was now only 60 ft. If the width was made more than was amply sufficient, that meant heavier gates and heavier works generally, costing of course a great deal more money.

Finally he should like to ask whether any silting took place in the channel, outside the docks; and if so, how that was met.

Mr. W. G. STRYPE would confine the observations he had to make to certain matters of detail, as the scope of Mr. Stileman' excellent paper was so large, and the subject so extensive. He woul refer especially to the mode in which the quay walls were constructe The paper stated that the plan of running the concrete in by mea of tubes had been abandoned in favour of the old plan of loweri the concrete by skips. The tube plan appeared to be simple a economical, and capable of being successfully employed if pro precautions were taken; and one of the most important of these that the concrete should be *poured* into the tube in very la quantities and as uniformly as possible, and some special arrangeme should be made to ensure this. The extensive and successful use concrete in the construction of quay works such as described in t paper had of late received great attention; and the plan of putti

acrete *in situ* had met with so much favour with engineers as d them to look forward to the time when the use of large ite blocks, with their extensive, cumbrous, and costly plant, be a thing of the past. For irregular foundations and uneven is there was everything in favour of placing the concrete . It would therefore be very interesting to have a little more iation as to the reasons that had led to the use of tubes being tinued; and also some description of the method employed, was not found to answer; if the tube arrangement could be sfully employed, it would be of considerable advantage in ting concrete in great depths of water. He should like to what depth of water the concrete was deposited in the present ce. The rise and fall of tide was considerable, and he should know how the panels were constructed, the method of placing and staunching them at the bottom; and also to what height respect to the rise of the tide they were carried up before the it was filled in, and to what extent in advance of the work the ing was projected.

Ir. G. B. Rennie asked why the three sections of dock wall late 35 showed such different modes of construction: Fig. 3 half rubble-masonry; Fig. 4 almost entirely lime-concrete; Fig. 5 rubble-masonry and lime-concrete, with cement-concrete e bottom. Also what was the object of the trench of cement-rete shown at the bottom of Fig. 4. Further it was stated in paper that, amongst other means used for excavating the dock, steam-navvy had been successfully employed. Would Mr. man kindly state what was the relative cost of excavating by the n-navvy as compared with hand-labour?

Sir James Ramsden, in the absence of Mr. F. C. Stileman, would wer some of the general questions that had been asked, leaving Stileman's son to reply to matters of detail. With regard to the struction of the graving-dock at the Devonshire entrance, he ite agreed in the view taken by Mr. Ormiston, that the entrance uld have been from the dock itself; but in the early days of the

docks economy had been one of the first things to be attended
had been found that the foundations of the north-east corner
Devonshire dock were very bad; there was a thick deposit
and other unfavourable material, and therefore the cheapest
access to the graving-dock was found to be from the sea.

With reference to the great width of the entrance to
dock, he ventured to differ from Mr. Ormiston, thoug
considerable diffidence. Although it was a fact that vesse
now being built without paddles, there were other circum
connected with the working of the dock which practical me
at once appreciate. Much longer vessels now frequented t
since the improvement of the channel and the opening of
docks; and it was important that these should be docked as
as possible, not only with a view to the safety of the vessels,
with a view to getting as many vessels as possible in and out
docks on the tide. It was found from experience that th
width of entrance at the Devonshire dock might be ver
improved. After considerable enquiry the directors came
conclusion that 100 ft. was the best width for that particul
way; and this had been proved in the most satisfactory ma
experience in working the dock. They now found that ships
length might enter the dock practically without putting
ashore; and this was due entirely to the great width of the e
Where there was a narrow entrance, it was necessary that
should practically be brought to a right angle with the
before she could enter; but with the present wider entrance,
alteration of the helm made the vessel describe the arc of
and she was not at right angles with the stream until
practically within the entrance of the basin. Again there
enormous area of dock at the back of the entrance, so that
desirable to contemplate the admission of ships in ver
numbers; and it had been found by experience that one vess
enter and another leave the basin at the same time. That o
was due to the extra width, which would no doubt save the ad
entrances that must otherwise have become necessary in the c
time.

[redacted]

regard to the question of silting, the water in Barrow
vas all pure sea-water; there was no alluvial deposit, and
ıtly no silt. The bottom of the channel was hard material,
ıd clay. Moreover the Island of Walney gave a double
both north and south; and it was a curious fact that,
the meeting of the waters of the Atlantic and the Irish
immediately opposite Morecambe Bay, the level of the tide at
2 ft. higher than it was at the estuary of the Duddon, nine
:her north. Hence for two hours after high water the tide
ing to the north, and when the water returned it was as clear
, so that any mud moved by the flowing tide was washed away
ea to the north. The dredging work had been very much
l by the scouring power of the tide. All that the dredgers
had been to remove the hard clay and gravel, the tide washing
finer material. He believed that two-thirds of the material
ıad been washed away by the operation of the tide.

reference to Mr. Ormiston's question about the level of
in the docks, he might point out that the docks were fed
ım of water called the Abbey Beck, which stream practically
d a depth of 24 ft. of water in the docks at all times.
ıl was the same as that of high-water spring tides, *i.e.*
er the outer cills; at neap tides, when the high-water
below this, vessels were admitted when necessary into
by locking. Experience had taught that it would have
er if the inner cill of the lock had been lower, from the
since the dock was designed vessels had become longer
ıer. In all that had been done at Barrow they had
red to advance with the times; but by the time they
ied a plan out, they always found themselves behind the
ents of trade. He had only to add that the whole works
. carried out by Mr. Stileman in the most satisfactory manner
rectors of the company, and that nothing could be improved
ay of practical details.

FRANK STILEMAN explained that the section Fig. 3, Plate 35,
lt outside the entrance and was tidal work; Fig. 4 was the return

wall in the basin and was all done with navvy work; Fig. 5 was the section of the Anchor Line basin-wall, where the same amount of work in masonry could never have been completed in anything like the time. The trench shown at the bottom of Fig. 4 was made to get the concrete through a layer of gravel down on to a good bottom. With regard to the material, all the tidal work outside was in cement-concrete, and that inside, in the dry, was in lime-concrete. With regard to the cost of the steam-navvy and of manual labour, in the hard stuff in which these docks were excavated the cost was found to be 4*d.* per cubic yard for the steam-navvy, as compared with 1*s.* 2*d.* for manual labour. These prices in both cases included the lead, but not coal for the steam-navvy. No doubt on railways, in remote places where men and lodgings were difficult to get, the saving would be still greater.

In regard to the question that had been asked with reference to passing concrete down wrought-iron tubes, the tubes were made 30 ft. long and 2 ft. diameter, and in three telescopic pieces of 10 ft. each, to enable them to be raised or slung as required: it having been determined not to carry the concrete higher than 3 ft. at a time. These tubes held a considerable amount of concrete; and it was found that, during the process of filling, a portion of the cement made its way out through the joints in the form of scum, leaving the first portion of each tide's work with less cement in it than there should be. Working as they were at 14 ft. below low water, it was found impossible to make the joints water-tight. Under these circumstances the method of building was altered. A steam crane was floated alongside the piling; the gravel and cement were brought alongside in barges, and the concrete was mixed on the barges, and lowered by the crane into the foundations, in Appleby's hopper-bottom buckets. It would thus be seen that the concrete was still deposited *in situ*; it was only the method of doing so that had been altered.

With regard to dredging, they had raised by dredgers alone from 3,000,000 to 4,000,000 cubic yards. The quantity raised varied according to the time of year; but taking it all the year round the cost was about 5½*d.* per yard actually raised. Taking

wever from Sir James Ramsden's point of view, *i.e.* including the antity removed by the scour, the cost was reduced to somewhere out 2*d*. per yard.

In reference to the construction and testing of the steel spring rders of the Buccleuch dock bridge, Plate 38, their top and bottom nges were of steel boiler-plates, 18 in. wide and 1½ in. thick; and webs were of Butterley channel iron, 3½ in. wide on the flanges, n. deep, and ½ in. thick. They were riveted up with steel rivets 1 in. m., the rivet-holes being rimered out when necessary, so that the ets entirely filled the holes. The girders were constructed with a ersed camber of 2 in.; and each when finished was accurately ted on bearings 25 ft. apart in the following manner, the results ng registered. A load of 32 tons was applied at the centre, and deflection and permanent set were noted. Successive loads reased by 10 tons at a time were then applied, and each time were lly taken off again, until 62 tons load was reached. This load then applied again and again repeatedly, until no further manent set was produced. The deflections were then noted both 55 tons and at 62 tons load, and were found to amount to $1\frac{9}{16}$ in. ler the former and 1¾ in. under the latter. The spring-girders ted direct on the pivot, and, when out of strain, had a reversed nber of 2 in.; so that when no moving weight was on the bridge, spring of the girders lifted the bridge off its front bearings; but girders were so adjusted that when a train came on they yielded ough to let the bridge down on its front bearings, while it was ed at the heel end by two wedge-shaped keys, fitted into jaws lted to the masonry, as shown in Fig. 8, Plate 37. In opening the idge, the force required to start each leaf was found to be 30 cwts.

The PRESIDENT proposed a vote of thanks to Mr. Stileman for his valuable paper, which was passed by acclamation.

The following paper was then read :—

ON THE STEAM-SHIP "CITY OF ROME."

By MR. JAMES HUMPHRYS, OF BARROW-IN-FURNESS.

The following paper is a brief description of the great Steamship for the Inman line, which is now to be seen in course of construction on the stocks of the Barrow Shipbuilding Company.

Perhaps the spirit and enterprise of British commerce have never been more fully illustrated than in the wonderful development of the mercantile marine in recent years. In 1870 the total tonnage of British steam-shipping was 1,111,375 tons, but the returns for the year 1876 show it to have increased to 2,150,302 tons; and from that time to the present it has been increasing still more rapidly. Not only has the total tonnage increased to this enormous extent, but the advance that has been made in increasing the size of vessels has been immense; and in no quarter has this feature been more remarkable than in the great passenger lines of the Atlantic. One of the foremost amongst these has always been the Inman line, which already possesses in the *City of Berlin* the vessel of largest tonnage at present in existence, with the exception of the *Great Eastern;* and whose steamers, with their high speed and excellent accommodation, are inferior to none in the world for the comfort and convenience of passengers.

With a view of still further providing for the comfort and swift transport of the rapidly increasing numbers who cross the Atlantic between New York and Liverpool, the Inman Steam-ship Company decided some little time since to order a vessel which should combine the highest rate of speed with the maximum of comfort and luxury: a speed but little inferior to that of railway travelling, and luxury and comfort such as can be found only in the most completely appointed modern hotels.

To fulfil these conditions it was deemed necessary that the vessel should be of very much greater dimensions than any ship then belonging to the Company; and after the most careful deliberation it was considered advisable to go to a size of at least 8000 tons. The dimensions finally adopted were, length between perpendiculars, 546 ft.; length over all, 600 ft.; extreme breadth, 52 ft. 3 in.; depth of hold, 37 ft. The great length as compared with the breadth ensured long easy lines for the high speed required; and the depth of hold being only 37 ft., as compared with the beam of 52 ft., ensured great stability and consequent comfort for the passengers.

General Features.—These are indicated by the general drawings, Figs. 1 to 5, Plates 39 to 41. It will be seen that the distinctive type of the Inman line has not been departed from in respect of the perhaps old-fashioned but still handsome profile, with clipper bow, figure-head, and bowsprit. For the figure-head is proposed a full-length figure of one of the Roman Cæsars, in the imperial purple. The whole of the headwork, with this exception, will be formed in iron, to save the cost and trouble of continually renewing the head-rails, &c., when made of wood.

The vessel is to be rigged with four masts, Fig. 1; and here again the handsome full ship-rig of the Inman line has been adhered to, with the addition of the fore-and-aft rigged jigger-mast, rendered necessary by the enormous length of the vessel. She will have three funnels, each painted with the Company's white band. The profile drawing, Fig. 3, Plates 40 and 41, gives a view of the general arrangement of the vessel, of her four complete tiers of beams, and of the run of the promenade and turtle decks, with the hurricane deck-house towering above all. A point calling for special notice is the large number of separate compartments formed by water-tight bulkheads, each extending to the main deck. The largest of these compartments are only about 60 ft. long; and supposing that, from collision or other cause, one of these was filled with water, the trim of the vessel would not be materially affected.

With a view of giving still further safety in the event of colli or stranding, the boilers, as shown in Figs. 6 and 7, Plate 42, arranged in two boiler-rooms, entirely separated from each o by means of a water-tight iron bulkhead. This reduces in nearly all full-powered steam-ships is a vast single compart into two of moderate size, 60 ft. in length; and in the e of either boiler-room being flooded, it still leaves the v with half her boiler power available, giving a speed of 13 to knots per hour. There is also the usual water-tight bulk separating the engine-room from the after boiler-room. Ano feature of great importance is the disposition of the boi They are eight in number, of the double-ended form, and arra fore and aft in four blocks of two, with the transverse bulkh already mentioned between the central blocks. This arrange provides for the bulk of the coal being carried in the sides of vessel; and advantage is taken to make the bunkers form part the structure. As shown by the plan, Fig. 7, they extend i straight line the entire length of the space occupied by the boil and, on one side, of that occupied by the engines also; and, being the same line with the outer side keelsons, they are incorpora with them, forming two strong longitudinal girders, as shown in transverse sections, Figs. 8 and 9, Plate 43. These add consider to the strength of the ship in the most important part, wh in many vessels there is rather a loss than an accession strength. It is intended further to make these bunkers keelsons water-tight, and so to form an inner skin, which afford admirable protection to the boilers and machinery in of the vessel being cut into amidships—an accident that in ordin vessels almost invariably causes instant foundering. These bunk and all the bulkheads, are fitted with proper water-tight doors, wh will be of the type adopted by the Admiralty. These will worked both from the main-deck and from below, and will be fi with tell-tales on deck, to show clearly whether they are open closed.

At the fore end a double bottom has been arranged in Nos. 1 2 cargo holds, for a distance of 150 ft. from the stem, Fig.

ate 40. This is filled with water-ballast, and will add atly to the safety of the ship in the event of her stranding on ock or suffering a bow-on collision, as the bow is thereby greatly engthened, and the risk of water getting into the vessel reduced. e sizes of the forward compartments generally are also small npared with the general dimensions. Constant care has thus been en in working out the arrangements, to provide as far as possible inst the dangers of collision or other accident.

Structural Details.—The stern frame or post, Fig. 3, Plate 41, now king at the Mersey Steel and Iron Works, will be the largest single ging ever made for such a purpose: the finished weight is estimated be not less than 33 tons, as compared with 18 tons in the stern st of the *Furnessia* of 5500 tons, also building in the yard.

The framing of the vessel is of the ordinary type, the floors ing 34 in. deep at the centre line. The frames are in one length om centre line to gunwale, and are of angle-irons 7 in. × 4 in., d 60 ft. in length. The reverse frames are also in one length of in. × 4 in. angle-iron. The butts of the frames, reverse frames, ad floors, are all carefully shifted from one another. The whole f the beams are of the Butterley bulb sections, each rolled in ne length. The vessel has two complete iron decks above; while he lower deck is complete for half the length, and has wide plating n each side for the remainder. She has nine tiers of keelsons, s shown in the transverse section, Fig. 8, Plate 43, all running right fore and aft; the five central ones are of uniform height, so as to be carried unbroken through the boiler seatings.

The shell plating, shown in Figs. 10 and 11, Plate 44, is arranged on a principle that has been applied with great success to all the large transatlantic steamers which have been built in Barrow. The inside plates form a complete skin, fitted accurately edge to edge and butt to butt, with covering-plates, half the width of the inside strakes, fitted outside. By this arrangement the shearing strains on the riveting are greatly diminished; and the plating in the way of the outside covering strakes being doubled, thinner plates are used than with the ordinary

mode of plating as per Lloyd's rules, and much sounder closer work is thereby ensured. The butt-straps for the whol the joints of the inside strakes are extended over the edge of plating, as shown dotted at BB, Fig. 10. The joints of the out strakes are also fitted with butt straps on the inside of the in strakes, extending the full width of the outside strakes, as sh dotted at SS.

The hold stanchions are arranged in two rows, one on each of the centre-line, the better to support and strengthen the l beams. The whole of the deck-houses, turtle-decks, and other erecti on the upper deck are of iron, to stand the strains of an Atla winter. The scantlings had to be considered specially, and h been approved both by Lloyd's and by the Liverpool Registry, vessel being built under the special surveys of both societies for highest class of ocean steamers.

Engines and Boilers.—The question of propelling this g vessel at so high a speed as it is anticipated will be obtaine namely 18 knots per hour—was one that demanded long and careful consideration. It was ultimately decided that it would better to adhere to the single-screw arrangement, and to adop propeller 24 ft. in diameter, driven by three sets of what technically known as Inverted "Tandem" engines, working on th cranks disposed at angles of 120° with one another.

The "tandem" engine, as is well known, has the high-press cylinder H placed in a line behind or above the low-press cylinder L, Fig. 8, Plate 43. This arrangement was adopted preference to other types of three-crank engines, in which powers developed are not so uniform, in order that absolutely eq efforts might be given out by each of the three engines, thus ensuri a perfectly-balanced and evenly-working machine: it is expected t when these engines are nicely adjusted, they will work almost with noise.

The general arrangement of the parts is shown in Fig. Each high-pressure cylinder is carried upon three wrought-i columns, thus giving plenty of light and easy access to the stuffi

d also enabling the cylinder covers, which are made in be readily withdrawn, should it be desired to examine or cylinders or pistons. The slide-valves VV are driven by an nt shaft S, worked by two pairs of mortice wheels, one at of the engines: an arrangement which has the advantage of comparatively small eccentrics. Moreover, as the valve lisposed towards the front of the engines, as shown in Figs. his arrangement makes them very accessible.

rank-shaft, Plate 45, is to be a built shaft, and, together screw shafting, is being made by Sir Joseph Whitworth heir fluid-compressed steel. The shafting is made hollow, e following process, which must ensure perfect soundness. gth is made from a hollow cylindrical ingot, which, while lten state, is subjected to a heavy hydraulic pressure, thus the exclusion of all gases, and thoroughly consolidating mass. The ingot is afterwards re-heated and placed on a and is then forged and drawn by hydraulic pressure, until ely assumes the form of a double-collared shaft. This n the writer's opinion, is the only one that can ensure nd and perfect shafting.*

eading particulars of the engines, Figs. 6 to 8, Plates 42 e as follows:—

are three high-pressure cylinders 43 in. diam., and -pressure cylinders 86 in. diam., all 6 ft. stroke. The of the crank-shaft is 25 in., and of the crank-pins 26 in. th of the main bearings is 33½ in., and of the crank-pins he crank-shaft, as built up complete, will weigh 64 tons; en made of iron and solid the weight would have been The propeller shafting is 24 in. diam., and the hole t 14 in. diam. The thrust shaft has thirteen collars, 39½ in. ring a surface of 6000 sq. in. This piece of shafting will tons. The propeller shaft is 25 in. diam., and 30½ ft. long, weigh 18 tons. The engine bed-plate will weigh 100 tons. ling surface of the condensers CC, Fig. 8, is 17,000 sq. ft.,

* See further particulars in discussion, page 351.

equal to nearly 17 miles of tubing. There are two air-pumps AA, 39 in. diam. and 3 ft. stroke; and two double-acting circulating pumps, 26 in. diam. and 3 ft. stroke; these pumps, and the feed and bilge pumps, are worked by levers attached to the aft and forward engines, as shown in Fig. 8. There is also a large centrifugal pumping engine, which can either be used for pumping heavy leaks or can also discharge through the condenser. There are three auxiliary pumping engines, for feeding the boilers, for bilge pumping, and for deck purposes.

Steam is supplied by eight cylindrical tubular boilers, fired from both ends, Figs. 6 to 9, Plates 42 and 43. Each boiler is 14 ft. mean diameter, and 19 ft. long, with a steam receiver 13 ft. long and 4 ft. diam.; and has six furnaces 3 ft. 9 in. diam., three at each end, Fig. 9: so that there are forty-eight furnaces in all. The fire-bars are 6 ft. long, giving a grate surface of 1080 sq. ft. The shell plates of the boilers are of iron, supplied by Sir John Brown and Co.; they are 24 ft. 8 in. long, 4 ft. 4½ in. wide, and 1¼ in. thick, and weigh nearly 2½ tons each; all the rivet holes are drilled. The internal parts are of Bowling iron; and each furnace has its own separate combustion chamber. These boilers are constructed for a working pressure of 90 lbs. per sq. in.

The engines are intended to work constantly at 8,000 indicated horse-power, although they are capable of developing 10,000 horse-power indicated.

Internal Arrangements.—The general arrangements of the passengers' and officers' quarters, &c., are indicated by the longitudinal section and plans, Figs. 3, 4, and 5, Plates 40 and 41. The promenade deck carries at the fore end the saloon skylight. In the hurricane deck-house the captain's and chief officer's cabins are placed, close to the steering-house and look-out bridge, so that they are always near in case of necessity. Abaft this is the upper saloon companion, and abaft this again the large upper smoking room, which is a novel feature in this ship: it being thought advisable, in view of the large number of passengers, to fit two smoking rooms, each with separate stair to the cabin deck. In

the after deckhouse is a deck saloon or lounge for ladies, which will be fitted up in the most elegant manner, and will prevent the necessity of going below in showery weather. Abaft this is a companion leading to the after end of the sleeping cabins. At the sides of this hurricane deck will be carried twelve lifeboats, one of which will be fitted as a steam launch. On this deck are also placed the capstans, and at each of the cargo hatchways are the steam-winches for working the cargo.

On the upper deck, Fig. 4, commencing at the fore end, Plate 40, is the steam-windlass for working the anchors and cables; and in the compartments on each side of the bow, accommodation is provided for the crew and firemen. At the after end of the turtle deck are all the washhouses and other fittings for the accommodation of the emigrants in the forward part of the vessel, together with cabins for the petty officers, and stores &c. for the ship. Next comes the upper saloon, or drawing-room, for the use of passengers. This apartment, which will be fitted up very handsomely with lounges round the sides, is in the form of a wide gallery with a large rectangular opening into the dining saloon below, thus giving great height and light to the latter apartment. Above this opening is a large skylight, richly ornamented; at the fore end will be a grand piano, and at the after end the grand staircase leading to the dining-room below. Proceeding aft we come to the gallies, sculleries, bakery, and other offices, all of which will be fitted with the best cooking ranges, &c. Next is the lower smoking room, which will be fitted similarly to the upper; the paneling of these rooms will probably be in wainscot oak, the floors laid in mosaic pavement, and the upholstery in morocco leather. Abaft this are the rooms for the officers and engineers, which, being exceptionally large and lofty, will be unusually comfortable. Under the after turtle deck is the accommodation for hospitals, lavatories, and other offices for emigrants, who are berthed in the after 'tween decks. At the extreme after end is the wheel-house, where will be placed the steam steering-gear, with a very strong hand steering-gear, to be used in case of the steam-gear breaking down. The steam-gear will be controlled by means of shafting from the bridge; from which there will be also a telegraphic communication, should it be desired

passage with large side-light at the end. This adds g
ventilation, light, and comfort of the passengers. The l
'tween decks is 9 ft. Next comes the grand dining saloon
52 ft. wide, and 9 ft. high, or 17 ft. in the way of the la
through the drawing-room above. This opening, surmou
skylight, forms a very effective and elegant relief to th
flat and heavy ceiling. It is intended that the paneling and
shall be highly artistic, and quite unique; special desig
in course of preparation. There will be three large a
small dining-tables, the large tables being arranged longi
the central part of the saloon, and the small tables at
in the sides: an arrangement that will enable the attend
more readily on the diners, and will also break the m
would exist if all the tables presented long continu
people. Each diner will have his own revolving arm
accommodation will be provided for seating 248 persons
large American organ will be fixed at the fore end of
Opening off through double spring doors is the foot o
staircase, under which will be fixed a handsome Americ
bar with the usual fittings; beyond is the saloon pantry
communicate with the kitchen above by means of two lif

On each side of the vessel, from the saloon to the

re comfortable than the usual ships' sleeping berth. The inner oms are fitted with the ordinary bed places, and light will be rnished from a 14-inch side scuttle.

Amidships are placed retiring-rooms, baths and lavatories, barber's hop, &c. Abaft the cabin bulkhead the main deck is fitted for bout 240 emigrants, in the same manner as for those forward; ccommodation is therefore provided on the main deck for 500 migrants in all. Accommodation can also be provided on the lower deck for 1000 emigrants more, making a grand total of 1500. In way of the engine and boiler casings will be fitted up the mail room, the specie room, and the passengers' luggage room, all opening off the main deck; and along the sides of the engine-room will be berths for the saloon stewards, &c.

In concluding the description of this great steamer it may be stated that her estimated weight, complete and ready for sea, is 8,000 tons, and that her displacement, at 26 ft. mean draft, is 13,500 tons; so that she will have a dead-weight carrying power of 5,500 tons. The cubical contents of her holds will give her a measurement capacity of 7,720 tons, at 50 cubic feet to the ton. She is expected to be ready for work in the course of next summer.

Discussion.

Mr. W. Boyd desired to congratulate Mr. Humphrys on the uilding of a ship which would no doubt be a magnificent specimen f the ship-builder's and the engineer's art. He wished however ask a question as to the method of working the valve-gear. As a le he thought engineers were pretty well agreed that on board ship ring was highly objectionable, where it could possibly be avoided; l it appeared to him that other methods might have been designed actuating the valves, which would not have been open to the ctions believed by most engineers to attach to gearing on board . He also felt some surprise that the boilers should have been

constructed of iron, and not of the excellent steel which the makers, Sir John Brown & Co., were capable of supplying. In fact he had fully believed them to be of steel, until he was now informed that they were of iron.

Mr. T. ORMISTON had recently had occasion to make a voyage in the *Orient*, which was built much after the style of the *City of Rome*, and could testify to its excellence. He was glad to see that shipbuilders and owners were following the example of the Guion Company in having the saloon amidships. He was rather surprised that in the *City of Rome* it was not so much amidships as it might have been, because the rolling and the pitching would be thereby very much diminished, besides getting rid of the smell of cooking, &c. He did not quite catch whether the ship was being built of iron or of steel, but he understood it was of iron. He had once had the opportunity of going over the *City of Brussels*, one of the largest ships then afloat, with Mr. Caird who built her; and he had remarked how very strongly she was built. Mr. Caird replied, "Well, we find that, do what we may, when we come to such long ships as this, it is difficult to make them strong enough, and it seems almost time that some other system should be adopted." On mentioning the matter afterwards to Mr. Scott Russell, that gentleman said, "That proves what I have long thought, that the system adopted, and very successfully adopted, in the *Great Eastern*, is one which shipbuilders, when they come to build very long ships will be forced into using."

Mr. E. REYNOLDS had nothing to say as to the construction of the ship, which had been determined upon after a great deal of consideration by persons who had had much experience in the building of long ships; but he rose to challenge a statement made by the author, that the particular way of making shafts which happened to be now in fashion was the only way of getting sound shafts. He did not wish to say a word in disparagement of the hollow shafts made by Sir Joseph Whitworth. Those which he had seen exhibited a workmanship which was beyond all praise. But

iat was not the question. He might say for himself that if he had ought hollow shafts were good he should have made them himself, id not waited for others to do so. It was true that a great many ad been made for ships of war, but no practical experience could be erived from those, because the first that had been made were not yet ; work; but all experience, and even all natural illustrations, tended, e thought, to show that hollow shafts were wrong. He had heard traws given as an illustration that Nature used the hollow-shaft rinciple. Now Nature was a very good guide if men tried to read er aright. But let it be considered what a straw was. It was the eed-carrying part of grass, and it grew up practically solid while it ad to stand the winds of spring; but for two or three weeks, while the corn was ripening, the shaft became hollow, and it answered its purpose very well in fine weather. In that way Nature's operations were always economical. But could anyone quote an instance of a hollow forest tree, which had to stand storms for centuries? or, if a forest tree became hollow by age, how long did it stand? His own experience was long enough for him to have had it as part of his duty to search for hollow axles on railways, and remove them as dangerous. Again, when the eminent firm of Whitworth had introduced hollow box-framing for engineers' tools, a certain class of engineers tried to introduce the same thing in steam-hammers. But an engineer's tool was a different thing from a steam-hammer: it was a large structure, in which nothing was wanted but rigidity; the strains were exceedingly small in proportion to the mass available, and there was never any shock. In that case nothing could be better than a hollow frame. But when the same thing was applied to steam-hammer frames, there came a difficulty. No steam-hammer with hollow cast-iron framing ever stood severe work; the frames broke because they were too rigid. A band of unstrained material about the neutral axis was wanted to keep the whole together, or else sudden fractures would take place. The reason why cracks were not immediately fatal in solid shafts was because there was such material about the neutral axis, and therefore the failure was gradual from the outside: and that was essential for safety. A 15-ton steam-hammer, with an 8-in. solid piston-rod, would stand four or five years;

but did any one expect that, if a hole 4 in. or 4½ in. diamete bored down it, it would last as many weeks? Apart from the g question of hollow and solid shafts, he challenged the statemen the particular method described was the only one by which forgings could be got sound. He could show in his own Com works much larger masses than were referred to in the paper, would have to be proved sound, and he was confident they wo proved so.

Mr. T. Adams understood the previous speaker to challeng statement that a solid shaft would not stand so much torsional as a hollow shaft, there being the same sectional area in both But it was well known that the resistance of a shaft to torsion as the cube of the diameter. Therefore the distance from the c or the arm, at which the mean resistance would act, must be greater in the case of the hollow shaft than in that of the solid and the sectional areas being equal, the resistance of the h shaft would be greater in the same proportion.

With regard to the boilers of the *City of Rome*, he certainl understood that they were to be made of steel. He had ha honour of making experiments with steel for boilers for the Bo Trade; and taking the steel of the Steel Company of Scotland, stood at the head of those experimented upon, the proportion its strength bore to that of the best Lowmoor plate was 167 t Some of the steels tried gave however a proportion of only ab to 100.

Mr. W. S. Hall wished to point out, in regard to n examples of hollow structures, that there was never any to strain upon a straw or a cane.

Mr. A. Paget observed that a friend had recently sent him bamboos from Hong Kong for some special work; and he feel much obliged to anyone who could mention any other natu artificial production which, weight for weight, had the same st and elasticity for torsion and bending.

. Reynolds explained that he had not been speaking of trength against torsion, but of endurance under long severe strains.

C. Marshall, looking at the question from an engineering iew, should like to call attention to two or three points ription of the machinery and of the ship. In the case of f that class, he thought the question of a twin-screw nt might have been more favourably considered. To ery high-speed vessel depend entirely upon one pair s seemed to him to be rather a risk. He presumed phrys would say that by the single-screw arrangement ned simplicity of construction and fewer parts. That up to a certain point; but he found that in order out that arrangement the designers had had to introduce rather a novelty—three pairs of tandem engines. itted that from an economical point of view it would better to have two sets of engines with cranks at right Engineers were pretty well agreed that the tandem nt was not the most economical form of compound quiring as it did something like $1\frac{1}{2}$ lb. more steam per an the ordinary right-angled arrangement. He did not there was any very great objection to the double-crank nt of engine, as to balance. He believed the arrangement s adopted in the *Arizona*, the *Orient*, and other vessels, made to work perfectly well, and with equal balance. osed superiority of balance however appeared to be the only y the tandem form of engine had been adopted in the *City*

reference to the point to which Mr. Boyd had called —the question of the introduction of gearing for driving s—he believed that to introduce gearing or millwright work amship (and he thought all marine engineers were pretty ed on the point) was a mistake; for every tooth introduced one of the wheels was an element of weakness. It would red that the whole efficiency of the engines depended upon

the teeth of the wheels, whether of wood or iron, retaining shape in the first place, and going on without breaking in the se place. He did not think the advantages of that arrangement commensurate with the great risks involved in it. As to advantage of getting small eccentrics, he was not aware that a eccentric was a radically bad thing.

With reference to steel crank-shafts, he should be glad i author would give some idea how the shaft was built up, how cranks were secured, how the crank-pins were secured, and how continuity of line and the accuracy of centre were mainta There was no question of more importance to marine engineers the question of crank-shafts, which in all steam-vessels were a source of weakness, and of possible loss, not only of money but of Any information on that point therefore would be of great value he believed Sir Joseph Whitworth & Co. were entitled to gratitude for having introduced the principle of built shafts. O question of the hollow shaft he thought there could be very doubt, though he thanked Mr. Reynolds for having brought the m before them. At the present moment he was himself introdu hollow shafts to a very large extent, and it would be very seri in the trial trips they should be found to give any trouble.

With reference to the arrangement of centrifugal pumps i engine, it would be useful to know why Mr. Humphrys pref the reciprocating pump for the purpose of driving such an enor volume of water as had to be dealt with in his condensers, inste a centrifugal pump, which gave a more continuous flow and extremely simple and effective. As to the boilers, he certainly sh have thought that, coming from Sir John Brown & Co., the p would have been of steel. The boilers were of a very large nearly but not quite the largest ever made, and it would be usef know how the shells were put together, and whether the joints (w as he understood were all drilled) were lap joints, or butt join double-butt joints.

Mr. HUMPHRYS explained the building up of the crank-shaf which there were three, all in line, one for each of the three eng

he construction was shown in Figs. 12 and 13, Plate 45, which presented one complete crank-shaft built up of its five separate ces. The double-collared hollow shaft, described in the paper as ng drawn to length while being forged on a mandril by hydraulic ssure, was afterwards cut into two half-lengths, to form the two le-collared pieces AA, which were bolted to the collars on the cent portions of the shaft. The two crank cheeks or webs BB first forged solid into the form of slabs, and then a small hole bored at each end, and enlarged by being forged on a mandril ed on suitable supports; thus ensuring that the metal was oughly worked in the most important part. The cheeks were rwards shrunk and keyed on the shafts AA, as shown in Fig. 13. hollow crank-pin C was drawn to length while forging, in the e manner as the pieces AA, but was not keyed into the cheeks Special arrangements had been made for heating the cheeks BB gas furnace.

The details of the mode of putting together were not yet finally led, pending the result of experiments now in progress; but liances were being schemed for ensuring absolute certainty as to the fts being dead true when put together. At present the work in gress was the manufacture of the separate pieces for the crank-shafts.

Mr. JOHN ROBINSON said his first impression had been that the lers were made of what he himself called "ingot iron," since it could rely be called steel; and he was surprised to hear that they were not. thought there must have been some difficulty, not known to him, to vent the adoption of such material as that now made by Sir John wn & Co., the Steel Company of Scotland, and others. Apparently would be a great advantage to reduce the thickness of the plates, and reduce the great danger of fracture in rolling. Plates for motive boilers, carrying 150 lbs. pressure, could be safely used h thinner than those described in the paper; those plates were of rmous size, but he believed Sir John Brown & Co. and others e quite capable of making ingot-iron plates of the same ensions; and as to the material which they could supply, he st say he had never met with any plates that would stand a

higher test or that were of more even manufacture. He had a plates from the Landore Works that were equally good. He comparing one works with another, but he was comparing o Yorkshire plates with a material of much more even quali invariably standing a much higher test. He therefore wished Mr. Humphrys why there had been any hesitation about u the boilers of steamships such plates as those made at the w which he had referred.

Mr. DANIEL ADAMSON rose as an engineer to put the matter b Mr. Reynolds and Mr. Adams a little more clearly before the m according to his own view. So far as the discussion had gone, not appear that the matter of hollow or solid shafts had bee altogether in the hands of Mr. Humphrys and the shipbu company. According to his own experience the purchaser freq said to the builder, "I am going to pay for the ship, and I will many of the vital conditions myself, and run all the risk as I t the responsibility." But apart from this, the work put upon a l shaft could be better understood and depended upon under a circumstances. The interior of a solid shaft was rarely consoli The press would probably consolidate better than the hammer. hammer bruised, where the press would send its force into the c and when with the press was combined the effect of the mandril the hollow shaft, he thought that from an engineering and mech point of view there could be no hesitation as to preferring the h shaft. He thought the subject was not exhausted by examining what was best for a shaft which had to bear torsion was only half the question. According to his experience, more broke down by a shock when the crank was on the centre, than torsion of the engine. There was often a hole in the very cen a so-called solid shaft. One of John Brown & Co.'s shafts of made for a blowing engine that he had constructed some ten ago, and forged too cold and under a light hammer, had before it had fairly got to work, and it was found to have a the centre 3 in. diam. Had it really been a hollow shaft, the facturer would have detected this unsoundness.

used a great variety of steels, including that of the Steel ny of Scotland, and he found them all good in their way and cial purposes; but because they were good for the purpose for they were selected, was it fair to say that they were superior to productions of the country? He would ask the members to ver all the tests that had been published in this country, and they could tell the best steel simply from the mechanical ions. And when it was known that the addition to the steel of cent. of carbon and manganese would double the tensile th and take off two-thirds of the ductility, it was certainly il to take into consideration rather what the material was, than it was made. He quite agreed with Mr. Robinson that no works could be found than those of John Brown & Co., to y a metal that was exactly what was wanted, for those who knew to ask for.

to the selection of the class of engine for the ship described in per, he could not conceive any better arrangement than to have pairs of tandem engines to work at high velocity, with great mity, with a natural balance, and without a pound of unbalanced weight. The whole arrangement appeared to him to guarantee mity of action, and hence great durability, considering the nt of material employed. He questioned whether the right-d engine was as economical as the tandem compound engine properly constructed. But there were a thousand conditions to ken into consideration, and he was sure a week would not suffice cuss them properly.

e regretted that the boilers were not made of what he would all ingot-iron, but would rather suggest should be called ingot-l. Compare the analysis of this metal with that of Low Moor —not common iron, although common iron contained only ounds that were exceedingly valuable when wisely used for r purposes: thus the much-abused Middlesbrough metal might ade to have a higher tensile strength than the purest Swedish But let them take the best Yorkshire iron, from any of the great s in Yorkshire, whose iron varied only in some small elements, d the control of anyone. If that Yorkshire metal were analysed,

of accidents in working, such as had lately taken
He was surprised that Mr. Robinson had not years
metal for his locomotive boilers; but now he appea
himself that the metal in question had greate
malleability, and greater ductility, when prope
the best puddled irons. But when great disasters
as to alarm even those best acquainted with the
surprised that the owners of such a magnificen
enormous ship which had been described shou
using a material of which they themselves could n

Mr. DAVID GREIG had attended the meeting
purpose of getting some information on the ques
was sorry to find discussions still going on up
had really been solved. What was wanted
that would make better boilers than the metal
wanted a boiler-making material, and they
could now get a material which was reliable to
gave no trouble, and did not produce half the was
Therefore to see ships of such a class as the or
paper being made of iron was most disheart
heard of steel boilers being tested in Glasgow, and
pressure; it was an unfortunate occurrence, but

prising; the responsibility of such a course was very great, and e responsible should look all round before coming to a decision 1 any question. It was true that a great deal had been done with l boilers, but those had been boilers within the ordinary limits of ufacture, not boilers of large steamers with very high pressures. difference between ordinary $\frac{3}{8}$-in. or $\frac{1}{2}$-in. plates and the $1\frac{1}{4}$-in. tes required for such high pressures was very great. Under present ditions he did not think it would be prudent to put steel plates boilers of the magnitude they were now considering. He had often l that iron was doomed; but where the interests involved were so ous and the experience so limited, it would in his opinion be rise to make an experiment of the magnitude contemplated.

Mr. Robinson wished to add that he had had some experience thick plates made of ingot metal, in locomotive engine-frames. firm had ordered such plates, and the firm in Sheffield already ded to had sent a material 1 in. thick, of which he should have n very well content to make boilers. The tests applied to those tes gave quite as high results as the tests for the plates of $\frac{7}{16}$ in. $\frac{1}{2}$ in. thickness, used for making boilers. He should have confidence refore in making large boilers of ingot metal 1 in. thick, and sidered there would be no need to make the thickness $1\frac{1}{4}$ in., ause the tensile resistance of the ingot metal was greater, and refore the plates might be thinner.

Mr. E. J. Cowling Welch said the plates to which Mr. Robinson uded had given a tensile strength of 27 tons per sq. in., with per cent. elongation, and the section of the metal at the point of cture showed a reduction of area of 52 per cent.; the fracture had fine fibrous appearance. The strain was put on by hydraulic wer at a slow rate, taking fifteen minutes to break the specimen; that it gave the fairest possible test. A number of experiments l been made with plates by various makers, and there had been difficulty at all in getting steel plates which would give much trouble in manipulation than iron ones. In fact now-a-days t Yorkshire plates could not be got with any certainty that they

could be flanged without splitting up, or that if a hole were the punching could not be split into two parts. The Yorkshire plates were getting worse and worse, while st were getting better and better. There was no diff manipulating steel plates, when properly understood. T not had a bad one during the whole year, while they had h of Yorkshire plates rejected at a great loss.

Mr. F. C. MARSHALL asked permission to refer to some e of his own with reference to the use of very thick *iron* illustrating the remarks of Mr. Adamson and Mr. Cramp had made some boilers eleven years ago, which he belie the largest ever made—16 ft. 6 in. in diameter, and 23 ft. l having ten furnaces. Those boilers were at work to th day; and he understood from the owners of the vessel, Guion of Liverpool, that they were in as good conditio day on which they were put in. They were iron boi together with butt-straps, everything being as carefully possible. Those boilers were a fair specimen of what coul with iron boilers; he should therefore have no hesitation what Mr. Humphrys had proposed to do with his vess plates he referred to were $1\frac{1}{4}$ in. thick, and they were at two vessels—the *Wyoming* and the *Wisconsin*. But he s that it would have been no experiment to introduce steel boilers of a vessel such as that under consideration. constantly making steel boilers with plates ranging from to $\frac{15}{16}$ in. He had not yet made a steel boiler 1 in. thick, shells of the boilers in question would have been only steel. Therefore Mr. Humphrys would at any rate hav 25 per cent. in the weight of the shells. He had at first be the impression, on reading the paper, that Mr. Humph introduced steel in the shells, and Bowling plates in the parts of the boiler. Some engineers were doing so, but he n as the result of his experience, it was a mistake. He ha which had been at work ever since Lloyd's had consente introduction of steel into steam vessels, now more than t

and to this day the scale made in the original rolling was not off nside, either on the furnaces or the shell-plates; and the boilers perfectly tight.

Mr. E. REYNOLDS wished to say a word of explanation with ence to the building up of steel cranks. He had probably made than anyone else, and he could state that there was no ulty whatever in getting them true. Of seven that had been away a month or two ago, only one required the centres to be ed after being put together; and of eight in hand now, only had required it, and that because they had large projecting bosses ne side. The scrapings did not amount to more than one-tredth of an inch. With regard to keying, he might mention he had one shaft which had been at work two years without any at all in the crank-cheeks or crank-pins.

Mr. C. E. COWPER desired to make a suggestion with regard to nomenclature of the metals under consideration. Year after year subject had come up, and they heard such expressions as "what ll steel," and "what I call ingot iron," yet they had no means of inguishing the varying degrees of hard and soft ingot metals. in, when a person spoke of "mild steel" it was not known how l it might be; and when another said he did not like steel use it was too brittle, it might be answered that some steel was ost as soft as iron. Why should not such confusion be avoided the general adoption of a simple series of numbers, say from 1 to No. 10, according to the proportion of carbon? The hardness steel depended chiefly upon carbon, varying of course to some nt with the amount of other ingredients, such as manganese. derate steel had 0·5 per cent. of carbon, and it might be called . 5. Hard steel, containing 1·0 per cent. of carbon, would be . 10, and very soft steel No. 2. If those numbers were used, it uld not matter whether the metal were called ingot steel, ingot n, or ingot metal.

The PRESIDENT could not allow the discussion to end wit
saying he was a little disappointed that steel had not been
liberally used in this ship. He hoped the next 8000-ton ship
in Barrow would have boilers of steel, and also be built of
steel, always supposing that a sufficient supply of the material
forthcoming, which he felt sure would be the case. Such
would be lighter, stronger, tougher, and altogether better.
experience was amply sufficient to show that boiler plates coul
got of good mild steel, and he rejoiced that the Admiralty
doing so well with steel ships and boilers.

He was sorry there had been no discussion as to the use of
decks, which increased the strength amazingly, making the ship
a veritable box-girder.

Mr. HUMPHRYS said in reply that some exception had been
to the use of gearing, for driving the shaft which carried the eccen
of the slide-valves of the engines. Many reasons had induced
to adopt that mode of working, and he thought they had the
possible warrant in the experience of years in all directions;
were hundreds of instances where vessels had been driven by gea
and in thousands of instances where, in large cotton mills and ro
mills and all sorts of places, gearing had been used with su
and without the slightest risk. Besides, everyone knew that a
of wheels, if the teeth were perfectly constructed, would
almost absolutely without noise, especially if one were made of
and the other of wood. He thought therefore that they need
trouble themselves at all as to the success of employing gearin
that purpose, more especially as, in order to make assurance do
sure, they had put a pair of the wheels at each end of the engin
that if one pair were carried away they would still have
other pair left.

There had been a great deal of discussion on the employme
iron plates for the construction of the boilers, as against
There again of course they had had a great number of matte
guide them. It was not a question of the owners' desire at
because the whole matter, the design of the ship, the design o

a, and all the details, had been left in the hands of the Barrow
uilding Company. They had been led to use iron in the
uction of the shells of the boilers, because they had found very
ntly in practice that, notwithstanding the greatest care taken in
anufacture of heavy marine boilers, and notwithstanding the
ig them an engineering job and not a boiler job—all the plates
drilled and shaped, hardly having a smith's hammer put upon
–notwithstanding all that care, and also notwithstanding the fact
efore the boilers were passed in the shop they had to be absolutely
om leakage, they still found that there was a tendency to leak in
ngitudinal seams. That was a very difficult thing to get over,
herefore they had thought it advisable to limit the number of
udinal seams to two. To do that they required plates of
tional length; and in consultation with Sir John Brown & Co.
were strongly advised by them to adopt iron, as they said they
roll the iron plates in their armour-plate mill of any size or
it, and would be able to ensure an excellent material. That
nent had been fully verified by the cuttings which had been
in all directions, showing that the metal was absolutely sound.
had been guided to adopt the iron plates for the purpose of
ng a more sound and beautiful piece of engineering work—he
l not call it boiler work. The members would have an
rtunity in the afternoon of seeing the details of the work, and
it had all been put together, which would be much better than
lescription he could give.

n observation had been made with regard to the saloon not
g so near the centre of the vessel as it might be. He might
tion that the pioneers of the system of midships saloons were
White Star Company; and he desired to take that opportunity
aying a tribute to Messrs. Harland & Woolf for the very excellent
ngements of their White Star vessels. The reason that had
rmined the position of the saloon in the *City of Rome*, was that
engines and boilers had to be placed in a certain position, not
forward, because the weights must be somewhere near the centre
the vessel; and that of course obliged them to get the saloon to
point just forward of the boilers. On examining one of the White

2 F 2

Star boats, it would be found that the saloon of the *City of Rome*, in consequence of the extreme length of the vessel, was relatively nearer midships than it was in those boats.

Some observations had been made by Mr. Ormiston as to the risk which might be run in dealing with vessels of that immense size, and how, notwithstanding all that could be done, such vessels could not be made strong enough. He desired to take exception to that; he thought they could be made strong enough, and that, if proper consideration were given to the workmanship, they might be made with great safety, and not occasion the least alarm: the Atlantic might do its worst, but it would never start a butt or a rivet in the work. He was glad to say that the system which had been adopted in the present case seemed to be able to ensure that degree of safety, because the vessels built upon that system had never shown the slightest symptom of weakness.

On the question of the hollow shaft he had expressed his views in the paper; and he thought, as a matter of common sense, where there was a hollow ingot to start with, which had been first squeezed out to a hollow tube, then put upon a mandril, and then squeezed again, outside and inside, a degree of soundness was ensured which could not be got by any process of hammering a solid shaft. But irrespectively of that, he thought there was a decided advantage in the hollow shaft. He expected more elasticity from it. He thought many a solid shaft in large steamers had broken from its very rigidity. The continual vibration of the vessel, where there was a solid iron shaft, might cause a fracture; but the slight elasticity of the hollow shaft might meet that difficulty.

They had had of course to consider the question of the single screw against the twin screw; and after weighing all the *pros* and *cons*, looking at the necessities of the trade and the docking arrangements, it had been deemed safest and most prudent to adopt the single screw. With regard to the question of the three tandem engines as against the other types, he thought they had been wise in adopting that system. They had three engines all interchangeable, so to say; so that any spare gearing that might be carried was applicable to each of the engines. They also had moderate-sized

ylinders, easily controlled; and there were a variety of considerations om the manufacturer's point of view which recommended that stem to them in preference to any other. So far as their perience had gone, they had reason to believe that better results d been obtained, in an economical point of view, from the tandem gine than would have been obtained from any other type, although thought there was not much to choose between them.

He had been asked why they had adopted reciprocating pumps. hey had had considerable consultation with the owners, who had ther expressed a desire that the pumps for circulating water in e condenser should be actuated by the engine itself; and there peared to be no objection to that plan, so far as their own views re concerned. They had a large number of such engines working ry satisfactorily, and there was no risk about the matter, so long the valves and the discharge were made large enough. The design s supplemented by a large centrifugal pump, which, in the event anything happening to the reciprocating pumps, could send water rough the condenser.

There was one other important matter, which as a shipbuilder he ished to bring forcibly before the steel makers present. The estion had been asked, "Why do you not build vessels of steel stead of iron?" He fully admitted the superiority of steel; but ter all, it was a matter of pounds, shillings, and pence. The ipowner was a merchant, and he regarded his ship as a machine r bringing him a return for the capital invested in it. If he was ld that he could have a vessel of much more perfect material, he ould reply, "It may be so; I am not a professional man, and do ot understand the matter; all I know is that Lloyd's and the Board f Trade give me all I desire as to certificates at present; I do not e the advantages, but, supposing they exist, what is to be the cost?" He must then be informed that the cost would be somewhat greater, so that he would have to pay so much more per ton of goods carried; and if so, he would say the game was not worth the candle. Nor would it be so until the price of steel assimilated to that of iron more nearly than it did at present. When that was the case, steel ships would be built universally, but not till then.

The Adjourned Meeting was held in the T
on Wednesday, 4th August, 1880, at Ten o'cloc
Cowper, Esq., President, in the chair.

The following paper was read :—

ON THE HÆMATITE IRON MINES OF THE FURNESS DISTRICT.

BY MR. J. L. SHAW, OF DALTON-IN-FURNESS.

The Iron Ore Mines of this district, as shown in the general plan, Fig. 1, Plate 46, are comprised within an area of eight miles from east to west and five miles from north to south: including the Millom district in Cumberland, which is separated from Furness by the Duddon sands, though the rock formation in which the mines are situated is continuous.

The mines of the district are entirely in the Mountain Limestone, though the iron ore is not exclusively confined to that formation. The mountain limestone (see the plan and section, Figs. 1 and 2) is bounded on the north by Silurian clay slates, and on the south by the Permian sandstone: the limestone is also overlain on the south by an area of about three square miles of Yoredale shales, which dip under the Permian sandstone. The limestone dips a few degrees south of east to the east of Haume Hill, nearly south at Stank, and in a westerly direction to the west of Haume Hill; the centre of upheaval being evidently the porphyritic rocks of Greenscow Crags, Fig. 2.

Besides the great faults alluded to in the Government Geological Survey of the district (on one of which Parkhouse mine is situated), there is another class of dislocations within the mountain limestone formation. With these a greater number of the largest bodies of ore is connected than with the main faults. Their bearing is west-north-west, and they dip towards south-south-west at an angle of very nearly 45°. These "slides" or "cheeks" are indicated in the drawing, Fig. 3, Plate 47, and may be seen in the mines at Lindal Moor, Dalton, Stank, Askam, and Hodbarrow. The slide at Stank mines is particularly observable, while at Hodbarrow mines the dislocation commences at the extreme east end and traverses the whole of

the mines in a west-north-west direction; thus forming as it we the very backbone of these extensive bodies of ore.

Besides these greater dislocations, the mountain limestone is c up by other and more numerous divisional planes; these howev the author has always looked on as being mere joints, and not havi the character of real dislocations, although they may carry veins ore, or "ginnels," as these are generally called in the district. T bearing of these latter joints corresponds very nearly with t magnetic meridian.

The dislocations and joints were in all probability the precurs of the iron ore deposits; the dislocations having been formed in basins of ore, and the joints into "ginnels," by the action of wa charged with carbonic acid and iron, the latter probably deriv from the slate rocks, as stated by Mr. Würzburger in the Journal the Iron and Steel Institute, Feb. 1872, p. 142. Although the auth does not think the theory of the formation of iron ore to be as y fully investigated, yet he believes this aqueous-chemical theory to by far the most reasonable one.

He has already remarked that the iron ore in the district confined—though not exclusively—to the pure limestone. T thickness of this is not much more than about 120 yards; at th depth it becomes impure, and passes into more impure and coars beds of schist, grit, and conglomerate.

The basins of iron ore do not exceed 1000 yards in their greate length, that being the length of the largest basin at Hodbarro mines, with a width of 430 yards. There are two other basins at t same mines, of 300 yards by 100 yards, and 500 yards by 250 yar respectively. These deposits are all more or less continuous, t thickness of ore in the largest basin being 100 feet.

The deposit next in size is at Park mines, 550 yards long fr east to west, and averaging 200 yards wide. The basin at Ask mine is 430 yards long and 250 yards wide. At Lindal Moor th is an almost continuous basin for a length of 1500 yards from no west to south-east, between the limestone and the clay-slate formati with a width of about 100 yards at the greatest; together numerous other deposits. Stank mine has been opened out to

ength of 770 yards along the "cheek" or slide mentioned above; ts greatest horizontal width is not much more than 30 yards, though here are numerous offshoots north and south from the main vein. The remaining "sops" or basins in the district are from a very few yards in size up to 100 yards, and the "ginnels" vary from 2 feet to about 20 feet in width.

The depth of these basins below the surface varies from about 10 fathoms to about 60 fathoms, never greatly exceeding the latter figure. There is an exception at Stank mine, where the ore is being worked at 100 fathoms depth; but this in the author's opinion is principally because the limestone only begins at a depth of about 60 fathoms, being overlain to that depth by Yoredale shales; while in the rest of the district the limestone is immediately under the superficial cover. The depth of the cover varies between about 20 feet and 33 fathoms, the latter being the depth at Hodbarrow mines. This was a very treacherous cover to sink through, consisting very much of quicksand.

The quality of the ore also varies considerably. It is divided into two great classes, the harder, which is got by blasting, and the softer, which is got by the pick only. The proportion of metallic iron in the ore varies between 50 and 65 per cent. Bars of stone and bodies of "muck," consisting of sand and clay, occur in the deposits; the stone being in general connected with the harder ore, and the muck with the softer variety.

The ore is generally worked height after height from the top downwards, as shown in Figs. 3 and 4, Plate 47; the main "soles" or levels LL, Fig. 3, being from 5 fathoms apart as at Hodbarrow mines, to 10 fathoms apart as at Park mines. Fig. 3 shows a gin pit, sunk about 6 fathoms below the top of the ore. Levels LL are driven from the shaft, leaving a "sump" for gathering the water, about 6 ft. deep. "Rises" RR are then put up to the top of the ore, and from the tops of these rises workings are driven out on the level. The method employed is first to drive to the farthest end, and then to rob the ore backward. As the ore is removed, the ground subsides gradually, crushing down the wood, which assists in

keeping back the clay, sand, or gravel from the next height workings below. The ore is bogied or trailed to the rises, in wl hoppers are placed for receiving it. From thence it is drawn the shaft by manual labour, horses not being employed in tl mines.

The next height is worked downward from the floor of the fi height, and is worked in a similar manner; and so on with the otl heights, until the main level is worked down upon. The size of t workings varies in general from 6 feet wide by 7 feet high to 10 f by 10 feet.

Fig. 5, Plate 47, is an ideal plan, showing a basin of ii ore, with position of shaft, levels, and rises. In practice t workings rarely approach the regularity here shown; Hodbarr mine is worked more nearly in this way than any other mine the district. Very little importance is attached by the writer to idea sometimes expressed of the iron ore having a north and so bearing; the result of his experience being that the iron ore depo in general lie on west-north-west dislocations, as already stated, as shown by the strong dotted line across the workings in Fig The lighter dotted lines outside the basin represent subordi joints or divisional planes, with which the "ginnels" of the dis in general correspond, as shown. The bearing of these joints nearly, though not exactly, corresponds with the magnetic no but it is clear that they must have existed before the ore deposited at all.

Fig. 4, Plate 47, shows the original shaft abandoned, and a permanent shaft sunk, in the limestone, to get the ore below the level. The method of working is similar to that given above. the largest bodies of ore however, where bars of stone and b of "muck" are absent, the workings are driven in a more re line than in the gin pits; and cross-cuts are put out from the levels, leaving pillars four to five fathoms square. There ma several of these levels in a mine, pillar being kept under pill much as possible. These pillars are finally worked out in manner given above, namely by going to the farthest end, robbing them backward.

In the mines worked in the harder variety of ore however, where the ore has been very hard and difficult to get, main roads and workings have in some instances been driven, and then "stoped" up to the roof or cover, leaving four-fathom pillars, which have been allowed to crush down: the ore has then been more readily worked.

The first shafts sunk are worked either by a horse gin or by a steam engine. By the time the ore above the first main sole is worked out, the second shaft has been completed; and as the first one is generally within the influence of the broken ground, it is allowed to collapse, as shown in Fig. 4. When an engine pit has been started however, it is generally arranged to place it out of the influence of the drag on the ground. When sunk in the limestone, these shafts last many years, in fact as long as they are required. The size of the shafts varies from 4½ feet square to 15 feet by 7 feet. One bogie full of ore is generally raised at a time, though at Hodbarrow mines two bogies are raised at once.

The ore has also been worked by means of open workings, as at Crossgates and Martin; a thickness of 30 feet of superficial cover having first been removed. This has proved a very cheap method of working the ore.

The mines are generally worked in two shifts of eight hours each, but in some cases the whole three-thirds of the twenty-four hours are utilised. Rock-boring machines, worked by compressed air, are pretty largely employed in the district, not for getting ore, which in general is too full of joints and other cavities to be worked in this manner, but for driving or sinking in the limestone; in this they effect a very considerable saving in time and cost.

The timber used in the pits is generally larch, though Norway timber is also used, at least for prop wood. In Plate 48 are shown sections of the working, explaining the mode of timbering. Fig. 6 is a longitudinal section of a main road or driftway, 7 ft. high and 6 ft. wide, as seen in cross section in Fig. 8. A course of timber consists of two forks A A, averaging 6 in. diam., supporting a headtree B of same size; the forks are "collared" or shaped to fit the headtree, and the latter is "nogged" with wooden plugs E to keep

the forks in their places; or in some cases iron "dogs" are u for the latter purpose. In order to keep loose material from falli into the workings, "spiles" or slabs of timber C C are driven lengthwise above the headtrees; they are generally 4½ ft. long 1 in. or 1½ in. thick. Spiles D D are also driven in someti at the sides, behind the forks; but generally only in the so portions of the deposits. Sole-trees are seldom used in the mine the district; and where they are used they are not laid across floor of the driftway, but lengthwise under the forks. In longitudinal section of the working, Fig. 7, the forebreast F is sh as being worked 10 ft. high: the forks are here 7 ft. high, in general 8 to 10 in. diam., and the headtrees are 9 ft. lo the spiles are driven above the headtrees at an angle, as sho and the overlying weight soon crushes them down flat on headtrees. In the transverse section, Fig. 8, is shown the c section of a 30 ft. pillar; one third of the pillar has not yet l worked, the next third is in process of working, and in the remai third the working is seen in the act of collapsing after the rem of all the ore.

The quantity of ore got per day by each man empl underground varies from one to three imperial tons, according to quality. The output from different mines varies from 100 ton 1000 tons per day; the gross output from the Furness dist exclusive of Millom, amounts to very nearly 1,000,000 tons annum.

The manner of making trials for ore is both by sinking trial and by boring. Formerly the usual method was by sinking pits; but as the workings became deeper it was found necessar employ boring; and this system, either with chisel borers or the diamond drill, has of late years been the common one.

The engines used in the district for drawing ore are gene horizontal high-pressure engines, though in some cases conde engines are used. In general they are not of greater power th to 30 horse-power. The pumping engines are for the most p the Cornish construction, having cylinders up to 70 in. diamete 80-in. engine is being constructed at Stank mine at the p

time, but about 40 in. is perhaps the most usual size. The greatest quantity of water raised from one mine does not exceed 2200 gallons per minute.

The district, being of a somewhat hilly nature, has enabled adits to be driven in a few places, as at Whitriggs and Parkhouse; thereby saving pumping to a height of 26 fathoms at the former mines, and 20 fathoms at the latter.

Discussion.

Mr. Edward Wadham said it might be interesting to the members to learn a little as to the uncertainty of working iron mines in the Furness district. Of all the mineral deposits with which mining engineers had to deal, there was nothing so uncertain as hæmatite iron ore. As described in the paper, it lay in joints and fissures of the limestone rock, and at the divisions between the limestone and the clay-slate rock below, and between the limestone and the new red sandstone rock above. As shown by the diagrams, the method of working was necessarily very irregular. The diagrams gave no exaggerated picture; in fact they were a little within the truth. In the first instance the ore was sunk upon, where it had been discovered or where it was supposed to lie, by means of a horse-gin; but in many instances, even at the present time, a still more primitive method of proving the ore was resorted to, namely by a jack-roll and a skip. The effect of working the iron ore, owing to the strata above not being really strata but drift, was that when the ore was taken out the surface collapsed, as shown in the diagram, and the pits got out of shape. It might occur to many to ask, "Why do you not sink a main shaft at once, and save the expense of sinking these temporary shafts, which have to be abandoned?" If the iron ore deposits were stratified, that would be a proper argument; or if there was anything

by which to form any reasonable idea where the iron ore was, what was its quantity, the argument would still be perfectly con But they were obliged, in working hæmatite iron ore, to feel their as they went on; and until they were satisfied that they had g deposit worth the expense of a rock-shaft and machinery, it was m economical to work with temporary shafts, and thus ascertain they were really going to get. The gin-shaft was sunk dow about 10 fathoms below the surface; then they first of all drove a horizontal heading to prove the extent of the ore. At the en this heading, where the ore was found to be cut off by the limes rock, a rise was put up right to the top, and from the top of that another horizontal heading was again driven out to the rock. ore was then taken off layer after layer, and gallery by gallery, they came down to the first heading, which served as a main during the time of working with the gin-shaft.

The whole of the ore above that heading was thus taken out, the timber was allowed to interlace itself and collapse, and superincumbent drift to fall down upon the timber, causing surface to break. Upon that broken surface it frequently happ that, in consequence of the rainfall, ponds of water accumulated. might be supposed that it would be dangerous to have these p just overhead, while the mines were being worked; but there was much danger in it, because a large amount of the surface gro consisted of clay, which, mixing with the water, formed a nat puddle, and made a water-tight bottom to the ponds. As a matte fact, those ponds had very seldom given any trouble; and as soo it was found that there was any leakage from them into the mi special pumps were put down to pump the water away at the surf and leave the top clear.

The engine-shaft in the diagram was merely shown upon its f operation. It was sunk down to a certain depth below where the had been worked out; then the main road was driven out from shaft, and the operation he had mentioned of getting the ore repeated. During the time this working was being carried on, operation of further sinking the shaft was also carried forward, the driving out of the next level below was also going on; so

time they had exhausted the upper section, they were ready to aking off another section below; and so on, until they found tom of the basin. This, he was happy to say, they had often rable difficulty in doing; for it sometimes happened that a pit commenced with being only 10 fathoms deep ended with being 120 fathoms deep. The whole deposit was so uncertain that impossible for any one to lay down beforehand any plan by a particular mine could be worked.

night be well to explain why the main shaft was sunk down 20 fathoms all at once, and then a rise put up again from the level to work the ore above; why they did not rather drive h time from the shaft, and take out each successive layer by a e heading. If a fresh heading were driven out each time he shaft, they would have each time a dead drivage to get h at starting, since all the limestone in the heading would be got out each time for no profit. As it was, the shaft alone own in the limestone, and the ore was taken out by means of ade in the ore, which paid as the work went on. It was thus conomical to sink the shaft and drive out from it in the way d been described.

e mode of arranging the timber was shown in Plate 48; and vorking out the first level they let down the spiling-boards d these, with the *débris* as it came down, formed a roof under they drove for the next level. Each level was close under the ove, and the roof of the upper level all settled down during the f working out the lower.

he PRESIDENT observed it was mentioned in the paper that some ginnels ran very nearly on the magnetic meridian. Of course s understood that it was not magnetic ironstone; but the ent might lead a reader to imagine that there was something tic about it. It was probably only an accidental circumstance.

r. WADHAM replied that in the Furness district it was found neral veins took more or less the direction of north and south; e hæmatite iron ore was in no way magnetic.

Mr. C. COCHRANE noticed a statement in the paper in referenc to the depth at which the ore was found, namely that at Stan mine "the limestone only begins at a depth of about (fathoms, being overlain to that depth by Yoredale shales." I would ask whether this did not offer some encouragement to se for red ore beneath the Yoredale shales, where it had not hither been explored. It was evident that the deposits of ore had tak place in the limestone before the Yoredale shales were deposited.

Mr. WADHAM replied that the experiment at Stank was t first that had been carried out to prove whether the ore exist beneath the Yoredale shales. These shales had formerly been tak for coal shales; and in the old records of the manor of Furness the was a statement to the effect that an owner of land had been fined the lord's court for sinking a coal-pit in his own land without t lord's permission: that was near to the Stank mine. There was record of any coal having been found in the Yoredale shales; believed however there was a seam of coal which might be detect by a microscope, found lying between two beds of shale.

Mr. SCHNEIDER said that the Barrow Hæmatite Co., bei anxious to ascertain practically what was the real fact with regard the Yoredale shales, had bored a hole 400 fathoms deep, but they h only found one or two fragments of coal; eventually they arriv at limestone. There could be no doubt that the remark made Mr. Wadham was perfectly true,—that they knew nothing whatev at present as to the real value of the district; they only knew wh they had actually got. He was one of those who thought there w yet a very great deal to be found that they had never yet dreamt Nothing was so uncertain and deceptive as the iron ore deposi The most encouraging ventures had ended in disappointment, a the most discouraging trials had ended in supreme success. Stank mine for instance, they had sunk for coal and found iron o It was a very remarkable fact that the "old men" who made pits Stank a hundred or more years ago (no one now could tell when was done) had sunk two pits twenty yards from each other. Th

was no reason why in the present working they should themselves have tried one of these pits rather than the other, except that one was nearer the main road, and therefore they had not so far to carry the material. Now if they had sunk in the further pit they would never have found Stank mine. They sank in the nearer, and came down into iron ore, after going through limestone a very few yards; but if they had sunk in the further, they would have gone down 55 fathoms in solid blue limestone without a trace of iron ore; the shaft would then have been abandoned, and Stank mine would not now be in existence. The same thing might be said with reference to Park mine, which had been very discouraging for a great number of years; at last, when it was all but being abandoned, they were told by the landlord that if they did not make one more trial they must give up the lease. He himself almost despaired; but he then put down a shaft in what appeared to be the most unlikely place in the country, and succeeded in meeting with the ore. They had been working at that spot ever since 1849, and from a length of 400 yards—the entire length of the deposit was 550 yards, but 150 yards belonged to a neighbouring mine-owner—they had already raised seven million tons of iron ore. The slate rock there came down at an angle of about 45 degrees and under-cut the mine; and at that end which might be called the north, because it was the farthest to the north, the ore was only 6 fathoms from the surface; but 400 yards to the south it was 25 fathoms from the surface; nearer the surface there was nothing but drift.

There was a very remarkable feature in Park mine, which was worthy of notice. In the centre of the mine there was a space of about 100 yards wide by 200 yards long, which was entirely drift—partly decomposed sandstone, or what they called "black muck," and partly white sand, so good and pure that they were raising 100 tons a week for use at the blast-furnaces. The ore lay all round this patch of drift. The depth at which the mine was now worked was 60 fathoms, and there the size of the patch was reduced by two-thirds, and there were already indications at the greatest depth that the ore was going clean under the patch, so that at the next depth, 70 fathoms, he hoped to find the drift altogether gone. There was also another

remarkable thing at Park, namely that at a short distance to the south-west there were other large pots, out of which they had raised hundreds of thousands of tons of ore. At a distance of 300 or 400 yards again to the west, there had been one of the most promising discoveries that had taken place of late years—a vein opening out in the middle of the rock like a fork. It was difficult to work, and it was an expensive place to make experiments in; they had therefore been cautious in not spending too much money until they knew that the place was worth working; but it appeared as if, in connection to a certain extent with Park mine, they were going to have for some hundreds of yards a regular vein of iron ore, quite different from the deposit found at Park, which was a solid mass with nothing like rock between it and the surface.*

Mr. DANIEL ADAMSON said that, the paper having pointed out the geological conditions under which the iron ore had been deposited, he thought they might safely come to the conclusion that the whole deposit had been formed since the formation of the clay-slate. Very few geological changes appeared to have taken place in the Furness district, compared with those in some other places. Taking the geological period from the old red sandstone, the ore seemed to have been deposited all through the period of the carboniferous formation and the magnesian limestone; and it had clearly ended with the beginning of the formation of the new red sandstone. Hence they must not be surprised to find it in large quantities, and exceedingly peculiar in its mode of deposit. It appeared to him that after the clay-slate had been thrown down, and while the mountain limestone was being deposited, the next upheaval would necessarily carry up the limestone, leaving fissures here and there, both laterally and longitudinally; for the rounded surface must necessarily have occupied a greater space than before, the originally deposited floor (if he might so call it) being lifted up on the mountain side; and hence it would leave crevices open, to be filled up with deposits of some sort. Judging from the recorded appearances of the limestone itself, he thought it

* For further details on this subject, see Mr. Schneider's remarks below, p. 377.

[cut]s very clear that this was not a case of faults through the rock, [cut]her by upheaval or depression; but that during the period of [cut]posit there had been a considerable amount of water action, as [cut]ustrated by the rounding off of corners in every direction.

He quite concurred in the statement of Mr. Schneider that [cut]was very difficult beforehand to estimate the extent of the deposits, [cut] to measure their importance in any way. They could judge of [cut]em comparatively, if from that immediate district they passed [cut]to another, where the formation must certainly have been much [cut]ieter and less disturbed. He would refer, for instance, to the [cut]oss section of the country from Manchester to the east coast. [cut]ginning at Sheffield on the coal measures, and passing to the east, [cut] that great district must certainly have been below water-level, [cut]d subject to a general depression. There a series of coal seams [cut]re found interlaced with sand, together with other indications, [cut]owing that there had been a series of drift deposits between [cut]ch seam of coal, resulting in a comparatively stratified rock. [cut]the ridge at Woodhead it was clear that the deposits must have [cut]en formed at about the water-level, and that afterwards the strata [cut]ust have been quietly depressed throughout the whole geological [cut]riod, without any violence, but not with uniform regularity. And if [cut]e ground did not come down with uniform regularity, there were [cut]ances that there might be breaks and ruptures which would lead [cut] crevices, even at the latest period just previous to the formation [cut] the new red sandstone. He thought they might consider that the [cut]hole of that time must have been an iron-depositing age, because [cut] that period in the history of the earth they had the whole series [cut] iron ores, especially those in North Staffordshire, showing that iron [cut]ust then have been abundant in one shape or another. Coming to the [cut]w red sandstone formation, overlying the iron, coal, and magnesian [cut]estone deposits, the iron period had not yet passed away, because [cut]ere were several places where the new red sandstone contained as [cut]ch as 20 per cent. of iron, and at other places it might range from [cut]o 10 or 12 per cent.; hence it was manifest that at that time the [cut]n had not ceased to be deposited, but that it was intermixed with [cut]rger quantity of siliceous or other matter.

The mountain limestone and the Yoredale rocks had been su
to a great deal of wear and tear by water, and had the greatest cre
and were therefore likely to contain the largest deposits. Loo
at the formation of the rocks in this way, he thought they woul
most likely to find the ore directly below the new red sands
where in that district the earth might have been comparativ
peace for some time, and the deposit might have taken place
considerable areas just before the great period of the new
sandstone deposit. It was clear from Mr. Wadham's explan
that there could be no means of judging of the ore deposits fro
lithological character of the rocks themselves, the whole being
disturbed a condition.

Mr. J. L. SHAW, in reply, observed there could be no doub
that iron was a very important constituent in almost all r
De la Beche in his researches gave the proportion of iron in all r
as averaging 2 per cent.; and $5\frac{1}{2}$ per cent. in the lowest stra
rocks, to which the clay-slate belonged. For his own part he w
opinion, seeing that iron was such an important constituent in
earth's crust, that it was hardly necessary for practical men to
upon any particular formation, or body of rocks, to account for w
the iron came from. Taking into consideration chemical agenci
conjunction with the important element of time, it seemed to
hardly necessary to suppose immense springs, or the ocean lar
charged with iron; for it had been observed, he believed by
Charles Lyell, that in such cases a little force acting for a long t
might be equivalent to a great force acting for a limited time.

The PRESIDENT proposed a vote of thanks to Mr. Shaw for
paper, which was carried by acclamation.

The following remarks by Mr. Schneider upon the rise a
progress of Barrow, during his connection with the Furness distri
were made by him in the course of the subsequent excursion
Windermere (see *infra*, p. 488), and are here inserted by h
permission.

y arrival in Furness for the first time in 1839, I was
ruck with the iron ore mines of the district, and felt
nvinced that under a proper system of management they
l far more satisfactory results than they had hitherto done.
e the production did not reach 1000 tons per week; but
refully through the district I felt satisfied that a more
ploration of it would yield satisfactory commercial results.
se of my progress I visited Barrow, which at that time
hamlet; in fact the total number of houses was nine,
of one farmhouse, two public-houses, and six labourers'
Acting on the impression made upon my mind, I procured
uke of Devonshire a royalty, on which subsequently the
rk mines were discovered. My first operations were
raging; but extending my research by taking property
owners, I established mines sufficiently encouraging to
to persevere. From the period that I have mentioned,
ow itself made no progress whatever until the railway was
he port. When that railway was opened in 1847 the
had only advanced to 300; and its progress continued
in spite of the facilities given by the railway for shipments
; so that at the commencement of 1859, some years after
ry of the Park mines, the population did not exceed 700.
ting very great discouragements in my searches for iron
having expended a very large sum of money, which
o be practically thrown away, and after having all but
the Park royalty, I was stimulated to one last effort by a
n the agents of the owners, stating that I must either
y search or abandon the royalty. I determined to make
arch; and having hitherto tried, as I thought, in the most
s, I now determined on a spot which appeared extremely
r the discovery of ore. Still in this I had formed a certain
opinion, which was now to be tested in a practical way,
k one last shaft; which, after going through six fathoms
but soil and gravel, came upon a solid mass of ore; and
ated Park mine was discovered. This was in the year
e production of Park mine rapidly increased, and it proved

so large a deposit of ore that the attention of my partner a
was attracted to the advisability of erecting furnaces for th
of the ore. The difficulty was the procuring of a sufficient
coke by railway, but this even at that time was in course of
and by the opening of the branch railway from Ulverston to
Durham was brought into direct railway communication
Furness district. The opening of this railway took pla
latter end of 1857; and during the early part of 1858 our p
matured, and we commenced the erection of furnaces at Ba
about 1st January, 1859. The result has been shown by th
Hæmatite Iron and Steel Works, which you have inspect
your visit.

"The population of Barrow at the time that we comm
erection of the furnaces was somewhere about 700. The
1861 gave a population of only 3,000, showing a comparati
though substantial advance in the state of the town. T
taken in the succeeding ten years was more marked, and t
of 1871 gave a population rather exceeding 18,000. I
period the rise of the town was still more rapid, and the p
increased in the next three years to the remarkable amount
showing an increase of 125 per cent. on the population
This result was mainly due to the establishment of the Shi
Yard, Flax and Jute Works, and other industries, which ca
considerable amount of labour. But the depression of tra
commenced about 1875 caused a cessation in the erection of
and naturally a considerable decrease in the large popula
had hitherto been employed in the building trade. This to
extent affected for a time the prosperity and population of t
but Barrow, after passing through the depression of the
years, has once more emerged from the temporary cloud ca
prosperity, and its population has once more begun to
remarkable manner. A private census taken by the corpo
1878 showed that the population had been reduced to 38,0
present calculation of the population is at least 44,000; a
present time there is hardly a single unoccupied house in t
borough. More than 200 have been erected during the pres

"It is a remarkable fact that, in spite of the disadvantages which ttend the sudden rise of a new town, pauperism has been singularly w within the borough. For many years up to 1878 the total uperism of Barrow—in-door and out-of-door—did not exceed about to 1¼ per cent.; and during the depth of the depression, which ached its climax during the last severe winter, the pauperism did t exceed 1½ per cent. upon the population. At this moment the duction has been so great that the present pauperism—as extracted m the last week's return to the Board of Guardians—only amounts 1¼ per cent. of the population of the town. It must be borne in ind that in a town like Barrow, where the working class are a great extent engaged in necessarily hazardous occupations, the mber of widows and orphans will bear a larger ratio to the total uperism than in ordinary cases; and it will not be forgotten that t present the total pauperism of Great Britain amounts to no less an 2½ per cent.

"One word in conclusion. In 1839 the production of iron ore in is district was only 1000 tons per week, and that of pig iron was l. Now the Barrow Works, alone, are producing at the present ment at the rate of 500,000 tons of iron ore per annum, and 1000 s of pig iron per diem; while the total estimated production of whole of the Furness district for this year is 1,100,000 tons hæmatite iron ore and 500,000 tons of pig iron."

'he following paper was then read:—

ON THE MANUFACTURE OF JUTE.

By Mr. WILLIAM FLEMING, of Barrow-in-Furness.

While Jute has long been known to the natives of Ben and largely used by them in various textile manufactures, and paper-making purposes, its introduction into this country i comparatively recent date.

In 1796 the East India Company imported some small quant of jute, and afterwards continued importing it in small lots now then; but it made no progress whatever with the manufacture this country. What was thus imported seems to have been empl in the neighbourhood of London, in the production of door-r ropes, &c. Portions of the samples however appear to have f their way to Abingdon, in Oxfordshire, where there were a manufacturers of sackings and woollen carpetings. There it spun by hand, and used up to a small extent in some of fabrics. The Abingdon manufacturers therefore appear to hav credit of being the first to employ jute in textile fabrics in country.

About 1833 some of the jute yarn thus spun at Abingdon sent to Dundee, where the matter attracted attention; and sh afterwards was commenced at Dundee that manufacture of which has resulted in such an extraordinary development of industry in Great Britain and Ireland, and on the Continent. increase in the consumption of jute during the last fifty years is remarkable. The total export of jute from Calcutta in 1829 amounted to 20 tons, valued at £60; it has now risen (in addi to the enormous consumption for manufacturing purposes in Ben itself) to upwards of 350,000 tons, or nearly 2,000,000 b annually, amounting in value to about £6,000,000.

Jute is mainly grown in Bengal, and exported from Calcutta. It is sown in March and April, and during the following three months attains a height of from 10 to 12 ft., while the stems reach from 1 to 2 in. in circumference.

Shortly after the plant has flowered, it is cut down near to the ground, tied up in bundles of from 50 to 100 plants each, and "retted," that is, steeped in stagnant water from eight to ten days, till the "bast" (or the fibre lying between the bark and the stem) can be separated from the wood. It is then removed from the water and beaten gently against a board, until, with a little management, the native operator can strip off the whole from the stem without damage to either stem or fibre. The fibre is then drawn through the water until all impurities are washed or picked off. It is then dried in the sun, and, after having been assorted into different grades of quality, is exported, under various distinctive marks, in bales of 400 lbs. each, to London, Liverpool, Dundee, Barrow, and other markets.

Softening.

The Jute Fibre being of a somewhat harsh nature, the first process which it has to undergo after being released from the bale, where it is very tightly compressed, is that of softening. This is done by dividing the jute into stricks or handfuls, and passing these stricks through between a series of heavy fluted rollers, which, by crimping and crushing, and in a manner rubbing the fibres, render them softer and more yielding.

The Softening Machine, Figs. 1 and 2, Plate 49, consists of four horizontal rows of fluted rollers about 9 in. diameter and 2 ft. 6 in. long, with ten rollers in each row. Each roller in the bottom or fourth row bears the weight of the three rollers above it, those in the third row are pressed by the weight of two rollers, and those in the second row by the weight of one roller. The stricks of jute pass first between the pairs of rollers constituting the first and second rows, then return between the second and third rows, and pass lastly between the third and fourth rows, being delivered in a softened

condition at the opposite end of the machine to that wh were introduced, and having been subjected during the p an increasing weight as they entered between the differ The softening of the jute is at the same time assisted by an called "batching," *i.e.* the sprinkling of the stricks with oil whilst they are passing through the machine. This is having two cisterns, one containing water and the other c oil, placed over the machine. Inside the cisterns are rollers which lift the liquids, and discharge them over a s doctor, so that they drop upon the jute as it passes bet rollers.

Breaker Card.

The jute having been softened, and weighed into bu conveyed to the Breaker Card, shown in Figs. 3 and 4, and 51.

The principal parts of this machine consist of a horizonta cylinder, 4 ft. diam. × 6 ft. wide on its working surface, cov sharp steel pins inclined slightly forwards in the direction the cylinder revolves; and of a number of small rollers round the periphery of the cylinder, each of these rollers b covered with pointed pins. The stricks of jute are laid or s the attendant upon an endless travelling sheet A, Fig. 3, whic them to the first roller, called the feeder; and the pins which surface of this roller enter the jute and carry it forward to where it comes in contact with the pins of the carding cylind surface speed of the pins on the feeder being about 10 ft. pe whilst the speed of the pins on the cylinder is about 20C minute and in the opposite direction, the fibres which ar presented and delivered by the feeder receive a severe co dressing from the pins on the cylinder before they ar released by the feeder. The cast-iron shell which en underside of the feeder for about one-sixth of its circu serves to keep the fibres embedded in the feeder pins, prevent their being carried off by the cylinder before being

carded. A large quantity of the fibre however, when struck by the pins of the rapidly revolving cylinder, is broken off and carried forward on the points of the cylinder pins; and it is to straighten out, comb, and split these portions that the other rollers, called workers and strippers, are applied.

The first roller that acts, after the fibres have left the feed roller, is the worker. This roller, which is about 9 in. diameter, is placed with its pin points at a distance of from 1-16th to 1-8th in. from the points of the cylinder pins. The angle of the worker pins is very much more acute than that of the cylinder pins, and inclined in the opposite direction. The worker surface runs in the same direction as the contiguous cylinder surface, but only at a speed of about 50 ft. per minute. The effect is that the fibres projecting from the pins of the cylinder are caught on the pins of the slowly revolving worker; and as the direction and pull of the cylinder pins tend to force the fibres on to the pins of the worker, a considerable portion is retained by the latter. The worker is in its turn cleared of fibre by the stripper, a roller about 13 in. diameter, the surface of which runs at a speed of about 430 ft. per minute in the opposite direction to that of the worker; and, travelling with pins inclined forwards, it strips the fibres from the worker, and is itself cleared afterwards by the still more rapidly travelling cylinder.

The same process is repeated at the second worker and stripper, which are placed rather closer to the pins of the cylinder than the first two rollers. After passing the second worker and stripper, the fibres are carried forward to the doffer, a roller about 16 in. diameter, which travels in the same direction and at about the same speed as the worker, and has its covering similarly arranged, except that in the doffer the pins are rather finer and more numerous. The pins of this roller are set close to those of the cylinder, so that the whole of the fibres are caught by them, and carried round to the two doffing rollers, which take the jute from the doffer in the form of a continuous broad sheet or fleece. This thin sheet of carded jute, after it issues from the doffing rollers, is gathered together or contracted from about 5 ft. to 4 in. by means of a tin conductor; and it then passes through the

delivery rollers in the form of a continuous sliver, and falls int
a can.

The surface speed of the doffing and delivery rollers is generall
about fourteen times quicker than that of the feed roller; consequent
if the jute be spread so that the feed roller receives about 2 lbs. p
yard, the sliver delivered into the can will measure about 7 yar
per lb.

The tin rollers shown under the workers and strippers have pl
surfaces, and are to prevent the fibres, as much as possible, fr
falling to the ground, when the stripper is clearing the worker.

FINISHER CARD.

The jute sliver as delivered by the breaker card is not conside
to be sufficiently carded for most purposes; and it is theref
necessary that the process of carding should be repeated on a seco
machine called the Finisher Card. The principle on which t
machine works is exactly the same as that of the breaker card; b
instead of only two workers and two strippers, there are sometimes thr
four, or five pairs of these rollers, and the pins on the surface of t
carding cylinder and rollers are finer and set closer to one another,
as to comb and split the fibres more efficiently. The finisher card
fed by slivers from twelve cans from the breaker card upon an endl
travelling sheet, similar to that used in the breaker card; which carr
them forward to be acted upon by the cylinder of the finisher in t
same manner as the stricks of jute are acted upon in the breaker ca
It will be understood that the slivers as delivered by the break
card, although continuous, must necessarily be rather irregular,
thicker in some parts than in others; but by putting twelve of th
already partially carded slivers through the finisher together, a k
of average is struck, and the slivers delivered by the finisher card
much more regular and even. The "draft," or proportion of spe
between the delivery rollers and feeder of the finisher card is ab
16 to 1; so that, being fed by twelve slivers, each measuring a
7 yards per lb., and these being subjected to a draft of 16, the sl
delivered by the finisher card will measure about 9½ yards per lb

Drawing Frame.

The next process after carding is to have the fibres of jute drawn t straight, and laid parallel alongside one another; and this is complished on a machine called the Drawing Frame, Figs. 5 to 8, ates 50 and 51.

There are several kinds of drawing frame, all intended to produce e same results; but the kind most in use is the system called the piral gill drawing-frame." In this machine the slivers, which ve been delivered into the cans from the finisher card, pass over a nductor plate and thence between three rollers, Fig. 8, which are lled the retaining rollers, and are in fact the feed rollers of the chine. Just in front of the delivery side of these rollers is a series of velling bars on which are fixed hackles or gills, *i.e.* brass stocks with el pins standing upright in them, Fig. 7. These bars, with the gills ached, travel forward from the retaining rollers, carrying with them jute fibres into which the pins penetrate, their speed being the same that of the retaining rollers, or just as much faster as will ensure t the slivers are kept tight and do not rise off the pins. The bars propelled by means of two longitudinal screws, one at each end of bar, cut at a pitch varying from 1½ to 2 threads per in. The end the bar which enters into the thread of the screw is bevelled to the gle of the thread, so that the body of the bar and the pins are kept te vertical, whilst the end fits the spiral. There is one bar in each ead of the screw, and when the screws revolve all the bars glide ward, supported on steel slides. These screws are called the top ews, and the length of their threaded part is made suitable for the gth of fibre, say about 10 in. or 11 in. for carded jute. As each arrives at the front or further end of the top screws, it drops from slide which has been supporting it in position, into the threads of o bottom screws placed exactly under the top screws, cut to the ne hand, but with a quicker thread and revolving in a contrary ection. These bottom screws accordingly carry back the bar, pported on bottom slides, and with its pins nearly upright, to the er end of the frame, where the thread of each screw is terminated a projecting cam, by which the bar is lifted up into the top screws.

again, close to the retaining roller, causing the pins of th penetrate the sliver which the retaining roller is deliverin a continuous forward travel of bars is maintained for 10 in. length in front of the retaining rollers, moving at what is p the same speed as those rollers.

At the front or delivering end of the screws, Fig. 8, whe drops down out of the sliver, are the drawing roller and the roller above it; the former being made of steel, about 2½ in. and the latter generally of cast-iron covered with leather, a diameter. These rollers, which are pressed together by weighted levers, move at a speed about 6 or 7 times greater retaining rollers or gills; consequently the fibres, when deli the gills as the travelling bars drop from the top to th screws, are seized between the rollers and drawn away from of the gills, which act as a kind of comb, holding them ensuring that they do not enter the bite of the rollers in a c tangled state.

The length of each travelling bar is about 3 ft., Fig. 5, a are fixed on it four gills, each 6 in. wide on the pins. Each se and gills, with its retaining and drawing rollers, conduct constitutes what is called a carriage; and drawing frames with one, two, three, four, or five carriages. Thus a drawi of two carriages, and four gills per carriage, will have eigh gills; and as two slivers from the finisher card are supplied to e the number of cans at the back of the machine will be Assuming the speed of the drawing roller to be six times tha retaining or feeding rollers and gills, it is evident that th delivered by the drawing roller will be six times longer th it enters the machine; and as there are two card slivers to e and each card sliver may be assumed to measure 9⅓ yards the sliver coming from between the drawing and pressing roll measure about 28 yards per lb. But, for the purpose of con the process of straightening the fibres and laying them par well as of more effectually equalising the slivers, it is necessar the jute through a second drawing frame; and therefore it convenient to unite the slivers from two gills upon a doubli

the purpose in front of the drawing roller, and so to sliver from all the eight gills comprised in the two rough four pairs of rollers D, Fig. 6, called delivery four cans; the sliver in each can will consequently ut 14 yards per lb.

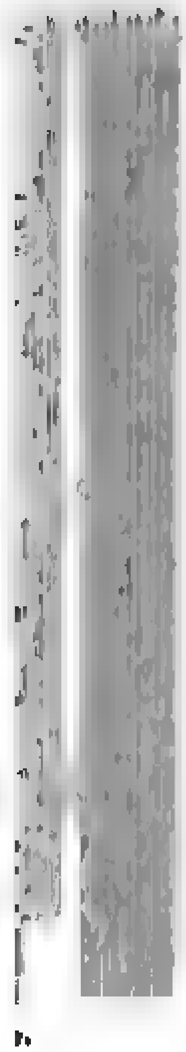
ınd drawing frame is constructed in an exactly similar the first drawing frame, except that the pins in the gills iner and ranged closer together; and instead of the two gills being united together in front of the drawing ivers from each gill are carried straight from the drawing y rollers and run into the can, thus making eight deliveries chine. As there are two slivers, each of 14 yards per lb., ach gill, the sliver as delivered into the can from this ing frame, if the draft on the machine is six, will measure lb.

ROVING FRAME.

t machine in the system of preparing machinery is the ne, Figs. 9 and 10, Plate 52.

ct of this machine is to draw out still further the fibres sliver, and wind them on bobbins in a form convenient process of spinning into yarn. The manner of drawing rs is exactly the same as that employed in the drawing as only one sliver is put up to each gill in the roving that sliver measures about 42 yards per lb., narrower gills serve the purpose, and eight gills can be fixed on each r instead of four; and in consequence of the slivers being hter, the pins of the gills are finer and set closer together. f the roving frame is usually about seven, so that the ered by the drawing roller of the roving frames will ut 294 yards per lb.

too thin a sliver to deliver into a can; and for that also for general convenience, the sliver is twisted l wound on to a bobbin; in this form it is called order to twist the sliver into rove and wind it on there are employed a spindle and flyer, constructed on



two rows in front of the drawing rollers, Fig.
speed of about 600 revolutions per minute.
turning freely on the spindle, is placed the
receive the rove. This bobbin is driven by ge
of the spindle and flyer, but revolves in t
The amount of twist given to the rove sh
sufficient to give it strength to unwind from
subsequent process, without allowing the fibres
suppose the suitable twist for rove to be on
sliver delivered; then the speed of the draw
arranged so as to deliver one inch for eacl
flyer; and the speed of the bobbin must be c
sufficiently behind that of the flyer to take up th
by the drawing rollers. For instance, the spin
600 revolutions per minute, the roller delivers 6(
and the circumference of the bobbin shank is 5
of the bobbin will have to be 480 revolutions per
than the flyer, because by lagging behind to th
will wind up 120 laps, each 5 in. long, or 600
But, as the bobbin fills, the diameter on which
increases, and the speed must be diminished
when the bobbin is nearly full, its circumferen
or three times what it was at starting: conse

of the bobbin is caused by a projection attached to the lifting rail being arranged to release a catch each time that the rail arrives at top and bottom of its traverse. The regulating motion is obtained from a bowl or pulley B with a leather face, which is made to revolve by contact between two flat circular iron discs rotating in contrary directions, Figs. 9 and 10. Each time that a catch is released either at top or bottom of the traverse, the bowl, with the shaft on which it is fixed, is allowed to slide inwards a little nearer to the centre of the two discs, Fig. 10, whereby its speed is diminished; and in this way the speed of the bobbin is also reduced for each successive lap that is laid on.

As already explained, the jute fibres in this slightly twisted form are termed "rove." But for the heavier classes of yarn (say when 1 lb. measures less than 400 yards), it is very usual to make the "yarn" on the roving frame. To do this it is only necessary to increase the twist sufficiently to give proper strength to the yarn.

Spinning Frame.

The object of this machine, Fig. 11, Plate 52, which completes the first stage in jute manufacture, is to reduce the rove which comes from the previous machine to the required size, and then to twist the fibres together so as to form what is known as "yarn."

The number of spindles in a spinning frame varies according to circumstances; but, for an average class of jute yarns, a very usual number is sixty-four on a side, arranged in a single row, at a pitch, or distance from one another, of $3\frac{3}{4}$ in. The main parts of the machine are the rack or creel for the bobbins containing the rove, the retaining rollers, the binding plate, conductor, drawing rollers, thread plate, spindles and flyers, and bobbins to receive the yarn. The bobbins containing the rove are placed on pins fixed on the rack, and the rove is introduced through a conducting plate between two fluted rollers pressed together, which form the retaining rollers, then over the binding plate and through a narrow conductor into the bite of the drawing roller and pressing roller: of these the former is of iron, while the latter is of wood and is pressed against the former by

means of steel springs. The drawing and pressing rollers run at a surface speed considerably in excess of the retaining rollers, the difference being regulated by change wheels to suit the size of yarn required. We will assume the drawing roller to be moving seven times faster than the retaining roller, so as to give a draft of seven. The slight twist which the rove has received in the roving frame gives it sufficient consistency to hold together and pull the bobbin round on its pin, so as to supply the retaining rollers; but when gripped at one end between the retaining roller and its pressing roller, and at the other end between the drawing and pressing rollers, the latter pair moving at the quicker speed, the slight twist which the fibres have received does not prevent them from parting. Not being supported by gills, as in the drawing and roving frames, the rove is made to press against the binding plate, in order to retain the twist, and so prevent the fibres from separating too easily and from passing through the drawing and pressing roller in an irregular manner.

By the draft of seven, the rove is elongated from 294 yards per lb as it enters the retaining rollers, to 2058 yards per lb. when it passe from the drawing roller. The fibres are twisted by the spindle an flyer in the same manner as in the roving frame; but the amount twist given to the yarn is very much greater than that given to tl rove, and the bobbin is not, as in the roving frame, driven by wheel but is dragged round after the flyer by the thread, and is retard by friction sufficiently to wind on the yarn, the friction beir regulated by the attendant to suit the strength of the yarn.

In illustrating the action of these different machines, a certa weight of jute has been assumed to be laid on the feed sheet of tl breaker card, with certain drafts and doublings in the separa subsequent machines; the result of which would be to produce ya known as "7 lbs.," because each "spyndle," or length of 14,4(yards, would weigh 7 lbs.: but by varying the weight, drafts, doublings, other sizes of yarn are produced. The finest yarns i jute, made from the best qualities, are about 1¾ lb. to 2 lbs. p spyndle, or say about ½ lb. per mile; whilst from the coarsest clas yarn is made of which a mile will weigh more than 30 lbs.

The yarns, having been prepared in the necessary forms for the ms, are woven into fabrics of great variety, suitable for the uirements of every market in the world, and these fabrics undergo ious processes of calendering, mangling, and finishing.

Jute is the cheapest fibre known, and hence the very general nand for jute fabrics in every country. Jute manufactures are r almost entirely used for the conveyance of grain, flour, rice, seed, coffee, pepper, saltpetre, &c.; as also for guano and all mical manures; while in the export of the raw materials, cotton wool, nothing else is now employed for packing. All makers of tile goods now use jute hessians and baggings for the packing heir manufactures.

The finer qualities of jute yarns are woven into fabrics suitable the production of curtain-cloths, tapestries, &c., for furniture poses (such as the "Kalameit," now produced in the Barrow Flax Jute Works), and for carpets, rugs, &c. They are also used gely, in combination with cotton, silk, and woollen yarns, in weaving of numerous ornamental goods. In fact the list the varied purposes, to which jute, jute yarns, and jute fabrics now extensively applied, is curious and remarkable, embracing, it does, telegraph cables, wire ropes, oilcloth and linoleum nufactures, ropes, twines, cords, &c., even down to artificial r.

The cuttings (or the few inches of hard fibre cut from the bottom the plant in India) are now largely used by the paper-makers in s country, as well as in India, America, and on the Continent; l the wastes made in the general manufacture of jute, which cannot spun over again, come into value in connection with paper-making, t-making, and other purposes.

This enormous and general demand has brought about a more an equivalent producing power in this country, in India, and ewhere; and during the past few years the jute trade has been ffering from the effects of this over-production; but as the equirements of the world are increasing so rapidly, the improved lemand must soon rectify this unfortunate state of things.

Discussion.

Mr. FLEMING exhibited an extensive collection
illustrating completely the successive stages of the manu
the original stems of the jute plant, to the finished
from the yarn. He also mentioned some statistic
extent of the jute trade, which he had omitted fro
According to the last government returns, at the end
were 117 jute factories in Great Britain and Ireland,
250,000 spindles, with from 11,000 to 12,000 looms, a
40,000 hands in the jute trade alone. In India it a
there were also 4,000 looms erected.

Mr. THOMAS ROUTLEDGE said that as a paper-maker h
used jute. The jute ends, or the refuse of the fibre, we
also jute waste when it could be got sufficiently cheap.
large sale for what was technically called in the trade "j
or jute ends, which were chiefly used for makin
paper. They were not much used for white paper,
process of bleaching jute was expensive; and whe
lost its strength. A very large quantity of brown pa
from jute ends and old gunny cloth.

Mr. C. COCHRANE asked whether the process of sac
carried on in the jute factory, and whether there wa
method of sewing the sacks up. He believed there
machines for the purpose, one of which he had seen at

The PRESIDENT desired to ask what was the length
fibre of the jute, and what the length when it arrived at
drawing-frame; also whether the "retting" of the fibr
done in cold water (which of course in that climate wo
be cold), or in actually hot water? He had also anoth
ask, with reference to the mode of laying the material

ıd of the feeder for the breaker card, as in Fig. 3, Plate 50. Were the ferent stricks of jute so placed as to break joint as far as possible, was simply a certain quantity put up from time to time? The ricks did not appear to be arranged as in the case of flax, but emed to be all mixed together. He should be glad to know the xact *modus operandi* of that part of the process. Also with regard o the screw-gill drawing-frame, he should be glad to understand whether the length of the frame represented the ordinary length of the jute fibres; or whether the fibres were not in reality very considerably longer, requiring to be cut down to the length of the drawing frame, as a more convenient length for dealing with, in the drawing process, than the full length of the original longer fibres; or whether the breaker card really did the work of shortening the staple. In the roving frame he observed that the roving was not twisted very much, but only just enough to hold together, so as to allow it to be further drawn afterwards in the spinning frame; if it were twisted much, it could not be drawn in spinning without breaking the fibre.

Mr. Arthur Paget asked what was the original length of the fibre in its natural condition, and what the final length as turned into yarn. It appeared, so far as he could judge, as if the length of the fibre were very great in comparison with anything else they were acquainted with; and as if the machinery were arranged—not, as in the case of ordinary machinery of that class, to avoid breaking the fibre—but almost to break it into lengths on purpose.

The President said that was the point upon which he desired further information; but he had not expressed it so clearly. Perhaps Mr. Fleming would give the actual length of the long and short fibres, and state whether any of the jute was worked by chopping the fibre to commence with.

Mr. Fleming said Mr. Routledge had remarked, with reference to the use of jute cuttings for paper, that in bleaching the jute it lost its strength. Probably in that operation the paper might

lose its strength; but they now had at Barrow a process of th
own, by which they could bleach jute without any such loss.

Their sacks had been sewn by machinery for many years. T
were now experimenting with three machines, one of which was q
new, and he hoped to have it ready to show to the members vis
the works.

The "retting" of the jute plant was done in cold water.
course the temperature of the water was variable, and it req
great care on the part of the operator, who had to be constant
the watch, feeling with his nail the state in which the bark
If it were allowed to remain soaking too long, it became decom
and discoloured. In some states of the weather eight o
days might be required, while seven days would suffice on
occasions. The sample exhibited of the actual jute plant,
he had received from an engineering friend, had been sent from
with a view of ascertaining whether any machine could be inv
which would do away with the necessity for "retting." The or
fibre was almost of a white colour, very valuable to spinners
in retting it lost that character.

With regard to jute cuttings, they consisted of about 8
9 in. cut from the lowest part of the plant. It often got
at that part, and mucous matter gathered around it; and some
8 in. or 10 in. were left in the water in rainy seasons; thi
cut off for the paper-makers, who could use it in their manufa
The cuttings came from India as such, separate from the rest o
plant, and were not sent to the paper manufacturers by the
manufacturers in England.

With regard to the process of carding, the attendant laid the s
of jute upon the feeding sheet with their root foremost, and bre
joint with one another. Any part of the root end that passed
the breaker card was cut by the first worker and stripper, and
taken up again by the carding cylinder. What passed on fu
was taken up by the second worker and stripper, and so it wa
combed out into an even body. In the finisher card again, the
process was carried all through. The length of the original
varied from 6 ft. to 7 ft. In all the operations after the br

card—that is, almost all through the process up to spinning—the fibre was about 16 in. long; in spinning it was about 6 in. long.

The jute took a very beautiful dye; but hitherto the colours dyed had been very fugitive. By means of the process he had already referred to, of bleaching without destroying the fibre, they could at the same time get permanent colours, such as a few years ago it had been impossible to obtain with jute fibre.

The President said he need hardly ask the members to pass a very hearty vote of thanks to Mr. Fleming for his interesting paper and observations. It was not always that they could get a manufacture of that kind so thoroughly described and illustrated with diagrams.

The vote of thanks was passed by acclamation.

The following paper was then read:—

ON THE STEEL-COMPRESSING ARRANGEMENTS AT THE BARROW WORKS.

BY MR. ALFRED DAVIS, OF LONDON.

The unsoundness of Steel Castings, particularly in the case of ingots made by the Bessemer or Siemens-Martin process, has given manufacturers considerable trouble, and occasions much waste of material.

A good deal has been stated and written of late as to the cause of this unsoundness, which occurs principally at the upper end of the ingot; but it appears now to be pretty generally conceded that the defects proceed from two distinct causes:—1st, the existence of gases, generated at the point of transition from the fluid to the solid state, which are imprisoned in the form of bubbles wher the surrounding metal becomes solid; and 2ndly, the existence o spaces formed by the natural contraction of the metal in coolin by reason of the outer skin first becoming solid, and refusing follow up the interior portion of the ingot, which subsequen cools, and consequently occupies a smaller space.

Various systems, designed to cure this evil, have already b discussed before this Institution. The system which is described, namely that of compressing fluid steel by the di application of High-pressure Steam, has recently been adopt the Barrow Hæmatite Steel Works, and by Messrs. Bol Vaughan & Co., and has the merit of simplicity combined efficiency. The arrangements adopted for the purpose are f upon those used by Mr. H. R. Jones of the Edgar Th Steel Works, Pittsburg, U.S., where the system has been wo some years.

The exact plan in operation at the Edgar Thompson Steel Works is shown in Plate 53, Figs. 1 to 4. A high-pressure steam boiler is provided, and communicates with a receiver or steam-drum R, which is attached to the side of the ingot crane and is furnished with a row of cocks corresponding with the number of ingot moulds. From these cocks strong india-rubber pipes convey the steam to the ingot moulds, which are ranged in the arc of a circle round the ladle crane, as shown in Fig. 1. The metal from the ladle is poured through a loose pouring cup, which rests on a conical seat at the top of the ingot mould, as shown enlarged in Fig. 3. As soon as the pouring is finished, this cup is removed; and a lid, having the steam-pipe ready coupled to it, is placed on the top of the mould, and secured to it by a steel cotter, as shown enlarged in Fig. 4. The cock on the receiver is then opened, and the steam allowed to act upon the metal until it has completely set. The result of this pressure is to make the ingot sensibly shorter than when cast in the ordinary manner, the difference, according to experiments made at the Edgar Thompson Works, being from 1½ in. to 2 in. in a 5 ft. or 6 ft. ingot. The ingots when cold are perfectly level at the top, and there is no porous head requiring to be cut off.

The arrangements at first proposed by the Barrow Steel Co. differ somewhat from those in operation at the Edgar Thompson Works, and require only a very brief explanation. The ingot moulds, which are of similar construction to those used by the Edgar Thompson Co., are not ranged in a circle, but placed in a row within a dock or siding, the centre line of which runs to the centre of the pit. The metal flows from the ladle into a trough mounted upon wheels, and provided with runners at points corresponding with the centres of the ingot moulds when the trough is in position. This trough runs upon rails, placed on either side of the row of ingot moulds, and can readily be removed after the moulds are charged. Each mould is provided with a steam-tight cover, having a wrought-iron pipe attached to it, furnished with a stop-cock. This pipe communicates at right angles with the main steam-pipe, which runs parallel with the side of the dock. The junction of the branch steam-pipes with the main is formed by means of a cast-iron sleeve-

piece, with stuffing-boxes, to enable the covers, with their respective cocks and pipes, to be thrown back out of the way when not in use. This plan was found inconvenient in many respects, and has been discontinued.

The arrangement shown in Plate 54 was designed by the author, and is now in operation at the Barrow Works. The ingot moulds are fixed in position in the same manner as at the Edgar Thompson Works (Fig. 1), but the method of securing the bottom joint of the mould is somewhat different. Fig. 8, Plate 55, shows a form of joint suitable for both the lid and base of the mould. Here V-shaped grooves are turned in the faces of the metal, care being taken that the diameters of the two grooves forming the joint are exactly equal. A ring of soft copper wire is then inserted, and the two parts are well keyed up with cotters, as before described.

The boiler for supplying the steam has been constructed by Messrs. Daniel Adamson and Co. It is 3 ft. 6 in. diameter and 9 ft. high, and is intended to be worked at a pressure of 200 lbs. per sq. in. The main pipe M, Fig. 6, for supplying the steam, follows the curve of the pit, about 12 in. from the side and 18 in. below the surface of the ground, Fig. 5. The branch steam-pipe B is of copper, bent to give elasticity, and has at one end the lid of the mould, and at the other a stop-valve. The stop-valve is attached to a hollow sleeve S, shown enlarged in Fig. 7, which revolves on an elbow attached to the main steam-pipe, and is kept tight by means of stuffing-boxes. The elbow has a blind end, and within the sleeve is pierced with holes, through which the steam passes to the branch pipe. When not in use, the copper coil, lid, and coupling can be thrown back, as shown dotted in Fig. 5, and, if desired, may fall into a pit made for the purpose, and covered over with an iron plate hinged at one side. No doubt other plans for applying steam pressure could be suggested, and various modifications will be necessary to suit different conditions of working.

At the Cambria Steel Works in Pennsylvania an attempt was made some two or three years ago to inject water through the cover

;ot mould, after the metal had been poured. The heat of
en steel of course generated steam, which acted as a
ng medium; a safety-valve being provided and loaded to
ure required. The disadvantages of this system, as
with that now described, are sufficiently obvious; the
ion of parts and the danger from explosions being very great.
results obtained by the process of casting ingots under
npression are highly satisfactory. Not merely is the ingot
sound, but the action of the steam is such as to enable
to work it earlier and in a hotter state than with the
method, so that there is an appreciable increase in the
The presence of the steam also acts beneficially on the
he mould, and causes it to last longer.
pressure necessary to produce a perfectly sound ingot will
pon the quality of steel to which it is applied. At the
hompson Works it is found that for ordinary rail metal
per sq. in. is sufficient. But for milder steel a higher
is needed; and since experience has proved that steam is
alt with at very high pressures, there does not appear to
eason why 1000 or 1500 lbs. per sq. in. should not be
required. It is only a question of giving sufficient strength
parts which are exposed to the pressure. As a matter of
oilers designed by Mr. Loftus Perkins will carry a steam
f 2000 lbs. per sq. in. with perfect safety. The question of
ght joints between the ingot moulds and covers with such
ssures is one of considerable importance; but there are
ys in which this difficulty may be overcome.* In using
a very high pressure the size of the supply pipe may be
bly reduced and the mode of attachment greatly simplified;
the amount of steam used is inconsiderable, the size of the
uld be correspondingly small As an alternative, in cases
gh pressures are needed for the consolidation of fluid metals,
r proposes the use of compressed air. With this system a
up to 1500 or 2000 lbs. per sq. in. may be obtained without

* See Plate 55, and below, p. 417.

danger or difficulty, as is completely demonstrated by th
practice at Woolwich, and by the experiments carried out b
Beaumont, in connection with the use of compressed air for
locomotion.

The advantages of an elastic compressing medium
consolidation of fluid metals, as compared with the l
process, scarcely need to be dwelt upon. In applying l
pressure a rigid piston is necessary; and the outer portion
cooling mass (which are the first to set) must be crushe
before the interior portions, which are still liquid, are
by the pressure. A considerable amount of power is w
consequence. In addition the fluid metal is forced against
of the mould, that is in a contrary direction to that which it
follows in the operation of cooling. With steam or compr
the operation is reversed: as soon as contraction comme
entire ingot is surrounded by a uniform pressure, which co
follows up the natural contraction of the mass.

In conclusion, the author would suggest that the pri
elastic pressure, in connection with the consolidation of flui
although at present applied to Bessemer ingots only, is we
the consideration of those interested in the manufacture of
of steel and iron castings, and particularly of heavy guns.

Discussion.

Mr. E. Windsor Richards thought it might be interesti
members of the Institution to be informed of what had b
in the matter of compressing fluid steel at the W
Messrs. Bolckow Vaughan & Co., Middlesbrough. To m
matter clear, he had photographed some ingots, one not com
and the others compressed. In order to show the structure
ingots, he had had them cut completely through from top to

if an ingot were simply nicked all the way round and then ten across, that part might be found solid, while the rest was . Thus Fig. 16, Plate 56, was an ingot, not compressed, which l been cut down the centre, and showed the cavities due to occluded gases. If it had been nicked across and broken at e line A B, it would have appeared solid, and that test would ave been deceptive. No outside turning or nicking across was ufficient. It appeared to him that the ingot in cooling had itself ried to get rid of the gas. The gas had gone to the centre, which of course remained fluid longer than the outside; as the steel became solid, it had compressed the gases right into the centre of the mould. The next ingot, Fig. 17, had been compressed with steam of the ordinary boiler pressure at the works, 80 lbs. per sq. in., and the effect could be seen: a considerable quantity of the gas had been driven off, but not all. A locomotive boiler had then been brought into the works, with 130 lbs. steam, at which pressure two of the ingots had been compressed; but it would be seen by the photographs of these, Figs. 18 and 19, that all the gases had not been quite driven out even then. Mr. Adamson was now making them a boiler to work at 250 lbs. pressure, which they hoped to have in operation in about a week. He was sorry they had not been able to get it at work previously, because he thought it would have shown that with that pressure they could get a completely solid ingot.

The next point was to determine what the gases really were. Old forge and mill managers, years ago, whenever they got into any trouble with their iron, always attributed it to sulphur. Latterly with steel the fault had been similarly laid on carbonic oxide. With a view of ascertaining what the gases really were, he had made a large tank, and dropped an ingot into it when filled with water. The ingot rested upon a drill 2½ inches in diameter, inserted from the lower side, with a stuffing-box to prevent the escape of the water; a pair of mitre wheels with a strap were attached to the drill. The weight of the ingot was 25 cwts., and this gave sufficient pressure to drill the steel. They were enabled in that way to put in a hole 2½ inches in diameter, and penetrating 4 inches into the ingot. The gases issuing

were collected and analysed by Mr. Stead of Middlesbrough, whose figures and analyses he confidently relied; the experime also been tried again a second time, and the second trial corrob the results of the first. It had thus been ascertained that t occluded in steel had the following composition:—

Hydrogen	78·6	per cent.
Nitrogen	20·4	,,
Carbonic Acid	0·2	,,
Carbonic Oxide	0·8	,,
	100·0	

So that it was not carbonic oxide gas at all, but hydrogen and nit It was quite clear from the photograph that the gases existed in in a high state of tension; and this was further proved by the quantity of gas got out of the comparatively small hole he described, from which 301 cubic centimetres, or 18 cubic inch gas was collected at atmospheric pressure. He therefore consid the process of compressing steel by steam pressure would be valuable. If all steel makers would take the trouble to slot t ingots in the way he had described, he thought they would surprised at the unsoundness revealed, and would arrive at conclusion that it was absolutely necessary to get rid of the g in order to obtain sound steel. It appeared to him that gases exi in steel almost in the same manner as carbonic acid gas existed soda-water; and it was only necessary to have sufficient pressur the top of the ingot to expel them altogether. He really thou that was the only theory which could be accepted; at any rat had the merit of simplicity.

The PRESIDENT said he did not understand the comparison soda-water. When the pressure was on the soda-water, the carb acid gas was dissolved in it; but when the pressure was low the gas escaped. Did Mr. Richards speak of expelling the mechanically from the steel, or of absorbing it chemically? Did metal absorb the gas under the pressure, as the soda-water abso carbonic acid gas; or did the pressure drive out the bubbles?

Mr. E. W. Richards considered that the gas existed in steel in a gaseous state, and was thoroughly mixed with it; it only required mechanical pressure to get rid of it. The ingots shown in Figs. 18 and 19 proved that the gas had been squeezed into the centre while the steel was fluid, and then forced out through the bottom of the ingot mould, the pressure being only on the top.

Dr. C. W. Siemens said the advantages to be derived by compressing steel in a fluid condition had been proved by Sir Joseph Whitworth, who for a number of years had produced steel of a very high quality, made in the open-hearth furnace, and subjected to very high pressure by hydraulic pumps while in the state of fluidity. Other steel makers had tried to arrive at the same result by similar means. This was perhaps the first paper that had been brought before them giving a distinct account of an attempt to obtain the same advantage by pressure exerted upon fluid steel, without resorting to the very thorough but expensive plan adopted by Sir Joseph Whitworth. At various times he had himself tried to bring pressure, resulting from the spontaneous generation of gases within the closed ingot mould, to bear upon steel; but he had not obtained altogether satisfactory results. Accordingly, when last year the subject of steam compression was brought before the Iron and Steel Institute, he immediately offered to make an experiment; but he had found that for mild steel, such as he operated upon, a very high pressure was certainly necessary. Sir Joseph Whitworth had found that 2 tons per sq. in. was the pressure necessary to produce solid metal. They now heard of 100 lbs. or 150 lbs. per sq. in. being sufficient to produce success; and from the photographs exhibited by Mr. Richards it was evident that a certain degree of success was obtained, although the holes in the metal were not entirely got rid of. In the case of very mild steel they were also troubled with holes near the surface, which they called honey-combs; and it was to get rid of these that the heavy pressure seemed to be necessary. The large cavities formed in the centre of the ingot would no doubt be, if not removed, very much reduced in size by such moderate pressure as had been mentioned; but he was quite certain that, in the case of mild steel, to get rid of the honey-

combs they would have to resort to a pressure of 1 ton, if not 2 tons, per sq. in.

With regard to the interesting question raised by Mr. Richard as to how the pressure acted upon the gases which had been occlude he confessed that he was in the same difficulty as the President. H could not conceive how, by applying pressure to a fluid mass, the could induce one ingredient out of several to go from the centre t the outside, or from the outside to the centre. The pressure was th same throughout over the whole surface; and all he could conceive wa that by that pressure the volume of say one cubic inch of gas would be reduced, if the pressure were high enough, to say one-tenth of cubic inch; or it might be that the gases would be reabsorbe in consequence of the pressure, and thus return to their forme combination with the steel. Mr. Richards had drawn a compariso between steel and soda-water. Now when the cork of the soda-wat bottle was lifted, the whole contents became a froth, and might called spongy soda-water. If the cork were pressed down again, t frothing would immediately cease, the gases being again absorb in the liquid. Therefore it was quite conceivable that by t application of a sufficient pressure to fluid steel, although the ga were not expelled, they might remain occluded in the steel. imagined that this would be the real solution of the problem. there could be no doubt that, if the cavities could be prevented the ingots, a great gain would be secured; and he should be glad see that, by the application of so moderate a pressure as was mentio in the paper, this result could be obtained.

While discussing the question of steel, he should be glad, with permission of the President, to make a few observations upon more general question of mild steel. Within the last week or a great deal had been said about this steel not being reliable, and t had heard of boilers giving way mysteriously under a very mode pressure. It so happened that he had been made cognisant of s of the circumstances regarding the failures which had been promine alluded to; and he might say that, although the first boiler failed under pressure, the second was found to be rent in preci the same manner without any pressure having been applied: ele

owing that it was not a case of weakness of the metal, under so ery moderate a pressure as 140 lbs. per sq. in.; but that from one ause or another the metal had been broken and cracked previous to testing. He could not speak as to the cause of the metal being in that condition; and he would only say at present that mild steel, properly made and properly put together, would not burst under any pressure whatever. If a boiler made of mild steel were subjected to an increasing pressure, it would be found impossible to burst it. And it was natural that this should be so. A material that would stretch 30 per cent. before rupture, would naturally give way first at the weakest sections, namely those through the rivet-holes; the round rivet-holes would become oblong, until sufficient water or steam leaked out to balance the amount of water pumped in or steam generated. That was not a mere hypothesis of his. He had witnessed some experiments made by Mr. Dean, the locomotive superintendent of the Great Western Railway, in the presence of Mr. Parker, the chief surveyor of Lloyd's, and described in a paper by Mr. Parker before the Inst. of Naval Architects* in 1878. The leakage began at 560 lbs., and the highest pressure reached was 800 lbs. Messrs. Easton and Anderson had also tried a boiler made of mild steel; and, in order to increase the severity of the test, between each trial they put the boiler into a furnace, made it red hot, and then took it out again, caulked it where it appeared necessary to close the seams, and then again subjected it to a pressure of several hundred pounds per sq. in. He believed that Mr. Greig had also made similar experiments. It might therefore almost be taken as an axiom that a steel boiler could not be burst; it might be made leaky, but that was all.

With regard then to the great question as to whether mild steel was a reliable material or not, he would answer most unhesitatingly that it was the most reliable material they knew of; they might punch, shear, bend it, or do what they liked with it, but they would not in any way destroy its tenacity. By way of practical proof he might mention one other fact. The steamers *Iris* and *Mercury* had been constructed of mild steel about three years ago for the Admiralty:

* See Transactions of the Institution of Naval Architects, 1878, p. 178.

not only the shell-plates of the vessels, but the angles and the of the boilers were all constructed of that material; and amo the plates and angles not one had been returned as defec quality. Since then the Admiralty had used steel for the const of their boilers and ship plates, almost to the exclusion of iro although probably more than 10,000 tons had been used, he b he was correct in saying that no plate had been returned as cracked or unsatisfactory, except a very few from mere mec blemishes. There had been no case of mild steel, properl and worked, giving way in a mysterious and treacherous mann

The demon of cheapness however seemed to be abroad, and settled especially upon steel. The works with which he wa particularly connected had introduced two qualities of mild one which was to compete for price in the open market; and a called "special metal," which was vouched for as being in eve reliable. This metal was not only made of more expensive m but it received greater attention, and was worked to a greater crop ends were cut off more resolutely than one could afford under all circumstances; and consequently it was rathe expensive to produce than ordinary steel. But he was sorry there were many engineers who, for the sake of £2 or £3 p preferred the unguaranteed material for the construction o boilers; others however took only the special or guaranteed m It appeared strange to him that there should be such a te to get cheap steel for the construction of boilers &c.; because, good iron boiler was wanted, Yorkshire iron was used, costin £22 to £40 a ton; whereas reliable steel plates could be obtai £14 to £16 a ton. The special steel plates thus cost a gre less than what engineers were willing to pay for the best Yo plates; but engineers would have the cheapest steel, at p £11 to £13 a ton, and took their chance. He thought it was dangerous policy, and one that naturally led to the dissatisfac which they had heard.

He might mention another form which steel now took, and had received his special attention: he referred to the product rivet-bars. For a long time engineers had continued to us

ivets for riveting steel plates together. He had always considered his was like stitching a silk gown with a cotton thread, making the itching material a weaker thing than the material to be stitched. atterly a certain confidence had been created in favour of steel for ivet-making; and great care was taken in producing rivet-steel of ach a quality as would make it perfectly reliable. But what was he fact? Since rivet-steel had been brought into the market, it was ot sold for so high a price as was given for the best rivet-iron. The tter cost as much as £19 a ton, but for rivet-steel engineers went own at once to the very cheapest quality they could get, which he night mention was steel rolled from crop-ends, and with all the lefects of crop-ends about it. It was therefore unfair to criticise teel severely, unless all the circumstances regarding it were known, nd above all things unless it was known what price had been paid for it.

Mr. THOMAS ADAMS had had the honour of making experiments for the Board of Trade on the strength of mild steel plates. The officers of that department had for some years been experimenting at Liverpool and elsewhere, without being able to get beyond about 500 lbs. per sq. in., or to destroy a ¼-in. plate. At the Steam Navigation Co.'s works in London they reached the unprecedented pressure of 1300 lbs. per sq. in., but still they could not destroy a ¼-in. plate. They then entrusted the work to him at Manchester, and he had succeeded in getting up a pressure sufficient to destroy any plates they tried, with only an inch ram, having a 6-in. stroke, and worked by hand. The highest pressure reached was 2050 lbs. per sq. in., without the semblance of a leak. The test they gave the joint was that they forced the pressure up to 500 lbs., and then took the pressure off, and measured the distortion of the plate; they then applied the pressure again, increasing it to 550 lbs., and measured the distortion again; and so on by steps of 50 lbs. up to 2050 lbs. The steel that stood the highest test was that of Dr. Siemens.

With regard to the subject of compressed steel, he believed the only benefits obtained were those derived from getting rid of the holes in the centre of the ingot. The interstitial spaces between the

In ordinary cooling, when the internal friction of th
the power represented by their mutual attraction b
the molecules could go no further towards one a
interstitial spaces could not be further filled up
cooling of the metal ; but the application of an
brought the molecules further in towards one an
additional surface of contact between them ; and the r
have a greater tensile strength than it would have
the natural way.

Mr. A. Paget asked whether the plates tested by
spherical, tubular, or flat ; also if he would state,
events, what the sizes were, in what way the join
what the test was.

Mr. T. Adams said the plates were flat surf
square. There was a frame 3 in. thick, with a
bolted at the back of it, which would not break ; an
destroyed was fixed in front by the same bolts. To
he simply took a piece of twine and laid it round an
a joint of two strands of twine inside and two out
bolts. The plate in front, under a certain amount of

Mr. G. J. Snelus had given some attention to the question of compressing steel, which was one that deserved to be followed up in a more scientific way than hitherto. Mr. Richards' illustration was that of the gases in a soda-water bottle; but this he thought was hardly to the point. Speaking from the chemical as well as the mechanical side, it was clear there were two ways of approaching the question of destroying these gas bubbles. One was by applying mechanical means for getting rid of them; and if the result were reached in this way, that would be sufficient for all practical purposes. But it was certainly important to find out why the desired end should have been reached in this way. Mr. Richards had mentioned that there had been rather a delusion as to the nature of the gases enclosed in steel; inasmuch as for a considerable time it had been supposed that the only gas contained in steel was carbonic oxide. It was true that for some time that view had been held: he thought it originated with Mr. Bessemer, who had told them that, in a very early stage of his experiments, he had put an ingot of steel, immediately after casting, into an air-tight vessel, from which he had afterwards drawn off the ordinary air; he had then gone on pumping, and had got an enormous volume of carbonic oxide. No doubt that was to a considerable extent a correct experiment, and there was a large quantity of carbonic oxide given off from the ingot during the time it was setting. But what he wished to point out was this: that during the process of blowing in the Bessemer converter there were a number of gases generated in addition to those which were blown through the metal. Air was blown through the metal, containing nitrogen, oxygen, and some carbonic acid; but in the process of blowing, carbonic oxide and carbonic acid were generated. At a very early meeting of the Iron and Steel Institute he had had the honour of reading a paper* on the composition of the gases which were evolved during the Bessemer process; and he had clearly shown that at the beginning of the process carbonic acid was mainly generated; and that, as it went on, carbonic oxide was the main product; and that, whereas at the

* See Journal of the Iron and Steel Institute, 1871, vol. ii., p. 247.

beginning there was about 10 or 15 per cent. of carbonic ac the gases coming out of the converter, the experiment finished a very little carbonic acid and between 20 and 30 per cen carbonic oxide. That experiment had been repeated by various investigators, and found to be correct. They had therefore co out of the metal, nitrogen, oxygen, carbonic acid, and car oxide; and it was a question which of those gases was retain the metal and formed the cavities.

As to this he wished to point out that there were two featu the case. There was no doubt that certain metals occluded ce gases. For instance, palladium would occlude hydrogen up to hundred times its own volume. It was clear that gas in that did not exist in the cavities only. Again, silver occluded ox but did not occlude hydrogen; it gave out oxygen at the poi setting. The well-known action of a globule of silver a moment of setting had been carefully investigated, and it had proved to be due to the oxygen, which had been occluded whil metal was in a fluid state, and was given out when the metal It was therefore clear that certain metals had affinities for ce gases, as palladium for hydrogen, and silver for oxygen; an thought it would be found that steel had an affinity for carl oxide, and occluded it. On the other hand, he thought it woul found that the affinity of steel—or rather of pure iron, because it hardly correct to call it steel—was less for hydrogen than carbonic oxide; and the consequence was that, when those gases all formed in the mass of metal together, carbonic oxide was prob occluded and sealed up in the iron, like hydrogen in palladiu oxygen in silver; whereas hydrogen was not so easily occluded, therefore remained in the cavities. Perhaps therefore they right in assuming that the bulk of the gas which came out of ste the moment of setting was carbonic oxide. Prof. Müller of Osnal had been the first to prove that the gases remaining in the cavi were mainly, as Mr. Richards had said, hydrogen and nitrog

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* See Proceedings Institution of Civil Engineers, vol. lvi., page 360; vol. lx., page 495.

hese he thought were very important facts to bear in mind in nsidering the question of getting rid of gases.

He thought further that it would be found there was another thod of getting rid of the gases, besides pressure. It was likely t, when pressure was applied, not only was the gas that was tained in the cells compressed into a smaller space—for he could believe that it was squeezed out—but also that the metal under t compression acquired a greater power of occluding those gases; therefore part of the gas might re-enter the metal in that occluded dition, while another part of it might simply be compressed. If ; was the case, it was quite probable that some chemical means ht be found for causing the hydrogen to be occluded in the steel ead of forming bubbles. It appeared from the experiments of Müller and Mr. Richards that those bubbles were not formed of onic oxide, but of hydrogen. He hoped therefore they might mately arrive at means of getting some constituent into the steel ch would cause the hydrogen to be occluded in the same way as the onic oxide was already occluded; and if this were done, it was r there would be no gas bubbles due to that cause. There might l be cavities due to the shrinkage of the metal in the interior, r the outside had set; and such a case at present was only to be ed by outside compression. It was therefore important to estigate the other side of the question—the chemical side—and see whether those cavities could not also be reduced by chemical metallurgical means.

Mr. John Hayes suggested that, if it were wished to derive the atest benefit from the application of steam pressure to fluids and lten metals, it would, in the present instance especially, be better admit the steam at both ends of the mould, rather than on the only. The practical application of that principle in a somewhat lified form might be seen in the duplex steam-hammer, as often ised for important forgings, as in welding up the rims of ught-iron wheels for locomotive engines. The application of ct steam pressure at the top would not be likely to cause that sure to penetrate uniformly throughout the ingot; and therefore

Mr. T. B. Sharp, who concurred with Mr.
the last six or seven years he had been experim
of metals; and he had succeeded by chemi
copper (notoriously a most difficult metal) perf
bottom to the top, in an ingot 4 ft. high and 7
been done by chemical means entirely. Cast
under any system of pressure was in his opi
and temporary, until the right chemical mean
for doing the work without pressure. This ha
realised in the case of copper. Taking a lad
he had poured some into one mould by the or
was very porous; and he had poured some int
treated it chemically, and it was perfectly so
difference at all in the analysis of the two;
their specific gravity, and, when rolled down, in
Had the porous casting been compressed and rol
sound it would have been full of "cold shuts
cast copper was so uniform that a piece plan
top of the ingot would show no difference as t
from a piece planed off the bottom or any othe
cast under pressure were formerly sold at 1s.

passed from the side of the mould into the metal and stopped there; and there was a third species of bubble, which in his opinion was given out in the act of setting. He considered pressure only got rid of the unisolated bubbles on the outside, which being connected with the outside atmosphere became gradually less and less, and were ultimately flattened up against the sides of the mould. The bubbles on the inside were simply reduced in diameter in proportion to the pressure; they could never disappear even under very intense pressure, unless, if such a thing were possible, the gas was forced into chemical combination; but the microscope had revealed the contrary in all the specimens of mechanically compressed metal that he had ever examined. Again, apart from the want of thoroughness and the costly nature of the pressure cure, a further reason why he considered the chemical method the true one, and the one which ought to be aimed at in steel, was that only the very simplest forms, such as bars or thick cylinders, could be treated by pressure; castings of a complicated nature could obviously be treated by chemical means alone. He apologised for having strayed in his remarks from steel to copper; but as all the same difficulties to be met with in casting the one metal were present in casting the other, he had done so with a view to directing the thoughts and experiments of steel makers towards what he had long suspected, and had recently found, to be the right groove as regarded copper.

The President said Dr. Siemens had mentioned a fact which was well known to some of them, namely that a mild steel boiler could not be burst with hydraulic pressure. He was perfectly convinced of that himself; but he thought some of the members who were not so fully convinced respecting it would like to have the satisfaction of seeing such an experiment performed, and he had asked Mr. J. T. Smith some months before to prepare a small experiment of the kind. The members would accordingly see in the afternoon, at the Barrow Steel Works, a small steel boiler,* 4 ft. in diameter and 4 ft. long,

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* This boiler stood 420 lbs. per sq. in., and then leaked so much as to overpower the pump. See *infra*, p. 483.

as shown in Figs. 20 and 21, Plate 56, which they would try to bu with hydraulic pressure, and he believed they would find that it impossible to burst it; they would simply make it leak badly.

Mr. ARTHUR PAGET asked if the author would kindly inform members whether it was within his knowledge that (as he was him informed), before the system of compressing steel by high-press steam was known either in England or America, a paper had b read before a sister Institution in France, embodying identically same principle, with the addition that the writer of that pa had found the action of the steam, in compressing the steel, assisted if there were the means of keeping the top of the in fluid for a longer time. Perhaps the author would state whet that was the case; because if so, as a matter of international court the name of the writer who had carried out the experiments written the paper ought to be known.

He should like also to ask the author whether he was aware (as he had been informed) a system somewhat parallel to the described, but using air as a means of communicating the pressure the ingot, was now in use at Bolton.

There was one part of the author's paper which he did quite understand. At page 400, it seemed to be implied that pressure by a ram on the ingot would have a different effect fr that of pressure by an elastic medium like air or steam. If object of the pressure was, as Mr. Richards' interesting rema led them to suppose, to cause the gases to sweat out of the met then it seemed to him there was no difference between the eff of the elastic fluid, steam or air, and that of a solid ram. If the other hand the idea was that, instead of the gas sweating through the pores of the steel, the pressure caused the metal combine chemically with the gas, then it appeared as if stea or air might have a better effect than the solid ram.

Mr. R. E. B. CROMPTON observed that, in the gases wh Mr. Richards appeared to have found to consist mainly of hydro and nitrogen, the proportions were very closely those that wo

form ammonia; and the ammonia being soluble in water, it was quite possible that the steam process might considerably aid the extrication of the gases from the steel by the combination of ammonia with the water in the steam.

With regard to the question of the occlusion of gases in iron and other metals, Mr. Edison in America had made a series of interesting experiments on wire—whether his published results had been confirmed by the researches of others or not, he had not heard,—and apparently had come to the conclusion that, if the whole of the occluded gases were expelled, the metal entirely lost its ductility, and became extremely hard. That was equally the case with iron wire and with platinum.*

Mr. R. H. Tweddell asked the author to state what was the specific gravity of the ingots after being subjected to the pressure, as compared with those not subjected to it.

Mr. Windsor Richards asked leave to mention that the gases he had referred to were taken from steel not compressed at all.

Mr. Davis in reply said that Mr. Richards' photographs showed that a moderate pressure had a decided effect upon the ingot, but that the pressure tried had been insufficient; and, as Mr. Richards had stated, Messrs. Bolckow Vaughan and Co. were now fixing a boiler to be worked at a pressure of 250 lbs. per sq. in. For ordinary rail metal he did not think more than 200 lbs. per sq. in. would be found necessary. At the Barrow Steel Works on the previous day several ingots had been cast under 175 lbs. or 180 lbs. pressure, and one of those ingots would be exhibited to the members visiting the works in the afternoon. One of the most important points was to apply the pressure directly after the pouring was stopped. In the arrangement he had suggested to Mr. J. T. Smith, which had now been carried out and was shown in Plate 54, the pressure could be

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* See First Report of the Committee on the Hardening, Tempering, and Annealing of Steel.

Siemens seemed to think, it appeared to him th
could be easily obtained. In the boilers constr
to which he had alluded in his paper, there
obtaining as high a pressure as could be desi
of conducting the steam at high pressure was gr
pressure, because they could work with a small
tubes.

Mr. Paget had asked whether he was aware t
had been applied in France. He was quite awa
and in the draft of his paper he had inserted
upon that matter; but that paragraph had b
believed on the ground that the Institution di
with priority of invention. As the matter had
might be allowed to read an extract from a
received from Mr. H. R. Jones on the subject:—
published in *Engineering* of 21 November 1879
'The Consolidation of Fluid Steel,' and signed '
that I first experimented on compressing steel
I have no desire to take from M. Considère one
his invention. It seems that we both hit on th
the same time, and being separated by thousan
be no doubt that it is a case in which the integ

Figs. 9 to 15, Plate 55, which had not been referred to in the paper, were simply sketches of methods for constructing ingot moulds. By the mode shown in Fig. 9 he thought they might dispense with one of the joints; there would be a conical plug at the bottom, which the weight of the metal would keep tight, and there would only be a top joint to contend with. After the ingot had been cast, the mould was intended to be turned over, and the ingot dropped out in the ordinary way. The joint shown in Fig. 8 he believed was one suggested by Dr. Siemens, in connection with Col. Beaumont's engines using compressed air at a very high pressure. Figs. 10 and 11 showed a joint for the bottom of the mould, designed by Mr. Henriques. There were two, three, or four wedges, wedging the mould down against the lips of the bottom plate. Figs. 12–14 showed an alternative arrangement, with T-headed bolts instead of wedges. Fig. 15 showed a joint designed by Mr. Charles J. Allport to be made of asbestos, which might be found a useful material. A good joint he thought might also be made at the top with a simple ring of copper wire $\frac{1}{16}$ in. thick.

The President moved a vote of thanks to Mr. Davis for his interesting paper, which was carried by acclamation.

The Meeting was then adjourned to the following day.

The Adjourned Meeting was held in the Town Hall, Barrow, on Thursday, 5th August, 1880, at Ten o'clock, A.M.; Edward A. Cowper, Esq., President, in the chair

The following paper was read:—

ON A NEW
REVERSING AND EXPANSIVE VALVE-GEAR.

BY MR. DAVID JOY, OF LONDON.

The Reversing and Expansive Valve-Motion, which is the su of the present paper, was originally drawn out by the write crude state, but possessing all its present elements, in the 1868-9; and has since been, at different times, the subject of freq investigation and experiment on his part. In 1877 he made special study, first working it out on paper, and afterwards testin the movements and positions by means of models. And thus, pas through innumerable forms under the correction of various error action, it has ended in the arrangement which is now submitted the Institution.

In passing, the writer may call attention to the fact, that this only one of the many instances where inventions are the res of a long course of work, followed in a given and definite directi and with a special end in view. It thus helps to disprove the theo of opponents of the patent system, who rather characterise inventio as lucky chances, which men of scheming brains fall upon witho expecting it. A few such cases do occur, just to give colour to t statement; but even these generally happen to men who have be working laboriously on some kindred subject.

In the writer's case, as an engineer, his attention has b specially directed by circumstances, and perhaps partly by t to the question of the movement of the valves in steam and o engines. As a pupil at the Railway Foundry, Leeds, he was thorou initiated into the mysteries of lead, lap, port, and travel, by investigation and observation of John Gray's valve-motion as ap

to locomotives, the first instance in which expansion was so applied successfully. Those who are familiar with the ingenious details and perfect action of Gray's motion will not be surprised at the strong bias thus given to the writer's mind in this direction; and the conviction was gradually attained by him that the proper distribution of the steam in a steam-engine is the very life and soul of the machine, and that the mechanism for effecting this object cannot receive too careful or too minute attention.

The great complication of Gray's motion and the difficulty of keeping it in order (partly owing to the very perfection and refinement of the action), were no doubt the causes of its falling out of use, and giving place to others more simple though less perfect in their action. These were again finally superseded by the very general adoption of the "Link Motion," now employed almost universally by English and American engineers, and very widely also on the Continent, though with a greater disposition there to depart from established usage. To the link motion the writer will refer in the following paper as the most satisfactory, because the most generally known, standard of comparison; and by this standard he hopes to show that a distinct advance has been made in the valve-motion now to be described.

The link gear in its turn became the subject of very careful practical analysis by the writer, while he had the charge of the rolling stock of a railway in the Midland counties; where the high price of coke rendered necessary a careful attention to economy of fuel consumption. Here he personally superintended the setting of numbers of valves, worked by link gears of various descriptions; and arranged them in many varied positions and proportions, all with the view of obtaining an even distribution of steam together with an equal lead; but all these contributed to prove the well known fact that it is impossible to gain both, and that in setting for one the other is seriously sacrificed; and further that the inequality increases as the expansion is increased. With high grades of expansion, and with the link gear as usually constructed, the lead becomes so excessive, and the point at which steam is admitted is so considerably in advance of the beginning of the stroke, that, although the

throughout the two leading desidera
increased simplicity and increased a
these methods was the device of givi
compound engine in the usual mann
the admission valve for the second cy
steam for expansion. Afterwards, v
direction, he employed live steam to
mechanical connection at all. Th
well in the case of reciprocating ma
steam pumps, etc., failed to give the
valves of engines producing a ro
back to strictly mechanical appliance
of the past and an increased knowl
laid down and worked out the valve-

Perhaps this is the place to rema
link motion has held its own so w
especially during the last few years, t
motion at once simpler than the l
errors, has engaged, both here and o
several engineers whose eminence is
attached to the subject. Prominent
Continent, the Walschaert gear, an

Referring now to the author's valve-motion, it may be premised that the original intention was to arrange a suitable valve-gear for the usual type of overhead marine engine, abandoning entirely the use of eccentrics, and taking vertical motion from the air-pump lever, in combination with transverse motion taken from the vibration of the connecting-rod. It is on this general principle that the valve-motion is arranged; in other words, the combination of two motions at right angles to each other, by the various proportions in which they are combined, and by the positions in which the moving parts are set with regard to each other, gives both the reversal of the motion and the various degrees of expansion required.

The action of the gear will at once be understood and followed by reference to the models, or to Figs. 1 to 3, Plate 57, representing an ordinary overhead marine engine; and to Figs. 4 to 6, Plate 58, representing a horizontal engine.

Referring to Fig. 4, Plate 58, from a point A in the connecting-rod—preferably about the middle—motion is imparted to a vibrating link B, constrained at its lower end to move vertically by the radius-rod C. From a point D on this vibrating link, horizontal motion is communicated to the lower end of a lever E, from the upper end of which lever the motion is transmitted to the valve spindle by the link G. The centre or fulcrum F of the lever E partakes also of the vertical movement of the connecting-rod, to an extent equal to the amount of its vibration at the point A; the centre F is for this purpose carried vertically in a slot J, which is curved to a radius equal to the length of the link G, connecting the lever E to the valve spindle. The slot itself is formed in a disc or sheave K, which is concentric with the centre F of the lever E at the moment when that lever is in the position given by the piston being at either end of the cylinder. This disc is capable of being partially rotated on its centre, so as to incline the slot over to either side of the vertical, by means of the worm and hand-wheel M, thereby causing the curved path traversed by the centre F of the lever E to cross the vertical centre line, and diverge from it on either side at will. The forward or backward motion of the engine is governed by giving the slot this inclined position on one or other side of the vertical centre line; and the

amount of expansion depends on the amount of the inclinatio the exactly central or vertical position being "mid gear." In th position steam is admitted at each end of the stroke to the amou only of the lead; and this is done exactly equally on each side of t centre line, the amount of lead being constant for forward a backward motion, and for all degrees of expansion. Thus wh the crank is set at the end of the stroke either way, the centre of the valve-lever coincides with the centre of the slot, and theref the slot may be moved over from forward to backward gear with affecting the valve at all.

It will be seen at a glance that, if the lower end D of the leve were attached directly to the point A on the connecting-rod, th would be imparted to the centre F of that lever an unequal vibrat above and below the centre of the disc K. The extent of inequal would be twice the versed sine of the arc described by the lower D of the lever E; and this would give an unequal port and uneq cut-off for the two ends of the stroke. But this error is corrected attaching the lower end D of the lever E to the vibrating link B: while the point A on the connecting-rod is performing a nearly ellipse, the point D in the vibrating link B is moving in a fig like an ellipse bulged out at one side, and this irregularity is so as to be equal in amount to the versed sine of the arc described the lower end of the lever E, thus correcting the above error, giving an equal travel to the centre F of the lever above and be the centre of the slot. At the same time the error introduced by movement of the end of the valve-link G is corrected by curving slot J to a radius equal to the length of G. These two errors however be set against each other, and a compromise may be made attaching the end of the lever E direct to the connecting-rod at and allowing the centre F to slide in a straight slot. By a balancing against each other of the errors so produced, and making the centre F of the lever E, and the centre of the disc to coincide at varying points in the travel of the former, a fair mot may be got for the forward gear of an overhead marine engine, giv a longer cut-off for the up stroke than for the down stroke. Thi of course at the sacrifice of the backward gear, in which the reve

the case; and the various degrees of expansion are between the two treme conditions.

Referring again to the equalising of the traverse of the centre F the lever E in the slot J, the unequal traverse may be either der-corrected or over-corrected, by shifting the point D in the rating link B nearer to or further from A; by this means a later int of cut-off may be given to either end of the cylinder at will, d the engine may thus have more steam admitted to one side of the ton than to the other, if required. The same thing may be done the lead. By altering the position of the crank for which the lever-ntre F coincides with the centre of the slot J, an increased or a minished lead may be given. The central positions and exact rrections are however in all cases standard and equal.

Hitherto the centre F of the lever E, which gives motion to the lve spindle, has been described as carried in a curved slot. This m is given as the most simple to manufacture, and for clearness te has been adhered to throughout the description. But if preferred e centre F may be carried by a radius-rod, in the manner shown in gs. 7 and 8, Plate 59, for a marine engine. Here the centre F is pported by a link L, and the other end of this link is carried by a igh-lever N N, whose fixed centre takes the place of the centre of e slot J in the other design. In the central position of this weigh-ver, the vibration of the suspending link L will make the centre F the lever E describe identically the same arc as if moving in e slot J while in its central position; and by rotating the weigh-ver N to either side of the centre line, the arc described by the nk will correspond precisely with the curve of the slot in either of s extreme positions, as well as in every intermediate position to hich the reversing lever may be set.

The peculiarities of this motion having now been described, it ill be evident that it may be applied wherever the link gear is now nployed: with this difference of general arrangement, that, where e link gear requires the centre line of the valve to be in the plane hich contains the centre lines of the cylinder and crank-shaft, this ar requires the valve centre-line to be set in the plane which ntains the cylinder centre-line but is at right angles to the crank-shaft

rolling-mill engines, and all other
Figs. 4 to 6, Plate 58, and in m
locomotives is given in Figs. 16 t
inside-cylinder engine: though it
equally suitable for outside cylind
engines, the arrangements are the
The gear has also been arranged wi
also from the extremity of the lev
lengthened for that purpose beyond
link G. The lines given by this w
are shown by the parallel dotted l
the similar lines in Fig. 11 repre
of expansion valve, applied on the
motion.

We now come to the advantages
the link gear for our standard, fo
these may be stated as follows. I
than the link gear by fully 25 pe
application in both. The writer ha
because he thinks it by any means
any engineer would assign to it, th
known, the first question asked by
any new invention which may be of
cost more than the old system?"

link gear are 5 tons 6 cwts. 0 qr. 25 lbs., those for the new gear are 4 tons 0 cwt. 1 qr. 27 lbs., showing a saving in weight, in favour of the new gear, of 1 ton 5 cwts. 2 qrs. 26 lbs., or about 25 per cent. The saving is not only in weight however, but also in the greater simplicity of parts, allowing increased facility for tooling and fitting.

Secondly, by placing the valve in the positions shown, namely in front in a marine engine, and on the top in a horizontal engine, a more simple and easily constructed form of engine is obtained. The cylinders also lie closer together, so that the engine is shortened in the line of the crank-shaft, see the dotted lines in Fig. 3, Plate 57. Thus in a marine engine space is gained in the engine-room, while in a locomotive larger cylinders may be got into the confined space between the frames; and, the cranks being closer together, room is left for increasing the length of the main bearings of the crank-shaft. All the centre lines of construction are also either parallel or at right angles to one another. Thus all the parts of an engine come direct off the tool, and go square together, without any inclined faces, such as require care in setting and are more costly in erection.

Thirdly, the new gear is more correct. In point of fact it is almost mathematically correct. By setting out the centre lines properly, a valve-path diagram is given similar to that shown in Fig. 9, Plate 60, where the lead and cut-off are exactly equal for both ends of the cylinder, and remain so in all grades of expansion to mid-gear; and where the port opens and closes by the amount given as lead at equal distances on each side of the centre line. The only variation is that the port for the rising stroke, in an overhead marine engine, opens a little wider than the port for the falling stroke. In practice however, for setting the valves of such an engine, it is only necessary to lift the valve on the valve spindle by the adjusting nuts, so as to allow say $\frac{1}{8}$ in. lead for the top and $\frac{3}{8}$ in. for the bottom. Then the points of cut-off will follow relatively in similar proportion, and valve-path diagrams will be produced as shown in Fig. 10, where the leads and points of cut-off for a 48-in. stroke are respectively $\frac{3}{8}$ in. lead and 37 in. cut-off for the rising stroke, as shown by the upper

line, and $\frac{1}{8}$ in. lead and 35 in. cut-off for the descending strok shown by the lower line. These, compared with parallel diagr Fig. 11, taken from a link gear, show the errors of the link correc the lead and cut-off with the link being $\frac{3}{8}$ in. and 35 in. for the ri stroke, and $\frac{1}{8}$ in. and 37 in. for the descending stroke. From latter distribution of steam, as given by the link gear, there greater pressure of steam to drive the piston down, when it is ass by the falling weights, and a less pressure for the up stroke in w all the weights are to be lifted. This produces the result shown i following Table, as compared with the result given by the new

TABLE OF TOTAL PRESSURES.

	Down Stroke.		Up Stroke.	
		Tons.		[illegible]
Joy's Gear	Mean Pressure = (cut off at 35 in.)	98	Mean Pressure = (cut off at 37 in.)	[illegible]
	+ weights falling =	2	− weights lifted =	[illegible]
	Total......	100	Total......	[illegible]
		Tons.		[illegible]
Link Gear	Mean Pressure = (cut off at 37 in.)	102	Mean Pressure = (cut off at 35 in.)	[illegible]
	+ weights falling =	2	− weights lifted =	[illegible]
	Total......	104	Total......	[illegible]

It will be seen that with the new gear the total effective pre is the same in both the up and the down stroke; while with the there is an inequality (in the case of the particular figures give about 8 per cent.: an inequality very noticeable when an engi running slowly, and, though hardly to be detected, still existing when the engine is at full speed. The equalising and relievin the strains by the new gear necessarily results in a more smooth equal working, and less wear and tear, than can be obtained wit link arrangement.

Further, an examination of the valve-path diagrams given b new gear, and a comparison of them with others of similar consti

iven by the link, will disclose another fact; namely that the ovement of the valve by this gear departs more widely from a ontinuously even speed than with the link motion; the acceleration s relatively augmented and the retardation prolonged, so that the alve receives a movement more resembling that produced by cams or appets, but entirely free from the jerks or shocks inseparable from hose motions, since the movement is here continuous. The circle, Fig. 15, Plate 59, shows the crank-path of a vertical engine divided nto eight intervals. While the crank is passing its top centre, hrough the interval marked A to B, the motion imparted to the valve caused by the centre F of the lever E, Fig. 7, swinging down the nclined arc in which it moves, while the lever action of E is almost spended. During this time the valve is being opened sharply by e inclination of the arc, and the result is a very rounded curve in e valve-path diagram, as shown by the full line on Fig. 12, Plate). During the next interval B to C in the down stroke, the centre of the lever is continuing to swing down the inclined arc; but the ver E itself has now begun to take action as a lever, and this action counter to, and partially neutralises, the movement of its centre F. he result is a longer dwell of the valve, at the time when it is fully pened, the effect of which is seen in the diagram, Fig. 12, from B to . During the next interval, while the crank passes from C to D, he movement of the centre F is almost *nil*, while the lever action of E is fully developed, and its motion is at its quickest. During this ime the valve is being closed, and hence comes the prompter cut-off, s seen in Fig. 12. In the next interval D to E, when the valve is closed, the lever action of E continues, though its effect gradually decreases, while its centre F is now swinging up the inclined arc; thus both are acting in the same direction, but, as one diminishes while the other increases, the result is to maintain the speed of the valve nearly constant, until approaching the point E, when a considerable acceleration takes place by the centre F swinging more rapidly up the inclined arc. This occurs just at the point required for the release, which is thus effected by a quick opening of the xhaust port as it is uncovered by the inner edge of the valve, iving the round full curve shown in the release diagram, Fig. 14.

of steam, still greater arise as we approach t
expansion. From the constant and unaltered
cut-off, coupled with the peculiar acceleration
to the valve, as described above, a sufficiently e
diagram can be obtained with a cut-off at one-thi
obviating the necessity for the employment of
expansion valve and gear. The full line in Fig
this diagram. It will be seen that the correct lea
up stroke) is maintained, the valve commencin
before the beginning of the stroke of the p
considerably increased opening for the port,
On the same Fig. 18 is shown dotted a pa
from a link. Here the lead, which for the fu
at $\frac{3}{8}$ in., is now increased to about $\frac{7}{8}$ in.; and
admitted to the piston about $1\frac{1}{4}$ in. before the be
Beyond the amount thus given as lead the port
and almost immediately begins to close again.

A number of less important but yet valuable
named, but these need not be enlarged upon.

The new gear is more accessible than the
working parts are brought down, and out to the
close together under the direct inspection

running, and no others: the difference of direction being simply due to the altered positions of the parts. Hence no duplicate parts are carried, such as are required in the link gear, in which a complete set of eccentrics, straps, rods, &c., have to be provided for backward running. The whole of these are continually in motion, notwithstanding that in forward running their motion is not only useless, but is even prejudicial to the action of the forward gear. In Atlantic steamers, for instance, this useless working is continued for about ten days together, solely in order that the backward section of the gear may serve for a few back turns on arriving in port.

Overhauling for repairs and for taking up of wear will also be more easily executed with the new gear, as the parts are removable more independently of each other; and one great source of wear, namely the eccentrics, is done away with.

This gear is also more easy to reverse, requiring less power than the link-gear; and the effect on the engine can be carried much further, as it is only necessary slightly to increase the angle of the slot J, Plate 58, or of the arc in which the lever-centre F swings, Plate 59, in order to increase the opening of the port, and prolong the action of the steam on the piston, so far that, in whatever position an engine might be standing, it would start. Hence in a marine engine it would never be necessary to reverse in order to get off the bottom centre; and in a locomotive there would be no need for backing, such as is often resorted to when an engine is unable to start, owing to the considerable lap given to her valves, for the sake of employing high degrees of expansion. In either case it would only be necessary to move the reversing lever forward beyond the usual full-steam notch (for which a provision is made), in order to permit the steam to follow the piston, if required, for even 9-10ths of the stroke; the engine would then have power to start, whatever the position of the cranks, or whatever the weight of the load.

Discussion.

Mr. Joy exhibited working models of the valve-gear for locom and marine engines, and explained its action.

Mr. F. C. Marshall said, as Mr. Joy had been good enoug mention his name in the paper in connection with the questic new valve-gears, he had ventured to show, Plate 65, his own v gear as he was at present fitting it to a large number of ma engines. The principle of this gear was precisely that adopted Mr. Joy, both of them arising out of the original invention of J Wesley Hackworth. It was the principle of a movable ce connected to the valve, which centre traversed an arc passing thro the centre of the reversing shaft, and coincided with that centre w in the dead position; thus securing a uniform lead at all points cut-off, and obtaining an equal cut-off at both ends of the str or otherwise, as might be desired. Six sets of engines were now work at sea with this valve-gear, indicating from 100 to 1800 H The action in the motion, as in Mr. Joy's, was simply perfect, so as the distribution of steam was concerned, as also in the relief strain on all the working parts, and in the means of giving slightly increased quantity of steam on the underside of the pist also in maintaining uniformity of lead, so that there was a unifo pressure at the top and bottom of the stroke when the engines w on the centres.

He scarcely liked to compare his own design with Mr. Jo but there was one advantage it possessed that he might point While they both attained the same objects, his design had o five working parts for each engine, instead of eight in Mr. Jo It was seen in Fig. 25, Plate 65, that the eccentric was opposite crank under all conditions; and when the crank was on either cen the valve connecting-rod and the main connecting-rod were para to each other. The valve-chest was fixed at the corner of cylinder casting, having an angular position in the plan, which

by making the pin-joint in the valve-rod parallel to the . The eccentric-rod, which with its strap was made usually el, extended to where the reversing shaft L was fixed, on keyed the arm K, Figs. 26 and 27; the extremity of the l the fulcrum for the suspending link J, the other end of ; jointed to the extremity of the eccentric-rod. For or working expansively, the reversing arm K was thrown ts opposite extreme position, indicated by the dotted line or into any intermediate position; this could be done by hat might be preferred, the screw gearing into a toothed as shown in Fig. 25, being merely a typical arrangement. of attachment for the valve-rod to the eccentric-rod was l in due relation to the throw of the eccentric, the stroke ine, and the lengths of the connecting-rod and eccentric-Mr. Joy's design he believed there was the same number as in the ordinary link motion. The only points of that he saw were the very long travel of the valve lever, hat of the connecting-rod, say ranging from 3 ft. to 6 ft. *City of Rome;* and the sliding motion at the opposite end er, in the reversing weigh-shaft sliders. Perhaps at the thirty days' voyage, or even an Atlantic voyage, some fficulty might be experienced in the way of repairs to the 'om the fact of the pin joints wearing out. Being attached mecting-rod, the lever would be subject to heavier wear tached to the ordinary eccentric, and so having a much ice to travel.

tortening of the engine-room, as claimed by Mr. Joy, was y small matter, because the length was generally governed ze of the condenser. His own motion was worked with eccentric instead of two. The smallest vessel worked in vas a yacht, belonging to Capt. Lee Guinness of Dublin. est power was that of the *Lady Tyler*, 1650 H.P. Figs. , Plate 66, were exact copies of original indicator diagrams a the *Osmanli*, the highest power indicated being 1409 H.P. -off, as shown, the power was varied from 1409 down to only the revolutions of the engine coming down from 57 to 35

the steam, and always secured uniformity of difference between Mr Joy's motion and his ow worked from the connecting-rod, while his o eccentric.

Mr. F. W. Webb said that, when Mr. Joy s he was himself busy designing a larger type of g endeavouring as far as possible to increase t having adopted 18-in. cylinders and 140 lbs. was difficult to get such large bearing surfaces to provide four eccentrics on the crank-shaft ; came to him he was busy at work with ano Hackworth's gear. He thought well enough of I ask his directors to have an engine built to try this engine itself had been sent down to Barrow examine, and to look into all the details at th meeting. The indicator diagrams, Figs. 23 and the working of the valve-motion ; and the mo details of the engine were also shown in Plat diagrams, one, Fig. 23, was taken at a slow perfect action of the steam in the cylinder ; an at higher speed, with an earlier cut-off.

There was another point in this engine, in valve-motion. It was not of course a new ide

stantaneously; and there was also a more sudden cut-off, as shown the diagrams.

The success in getting an increased bearing surface was well seen Figs. 17 and 22, Plates 62 and 63, showing an engine with 18-in. inders, placed 1 ft. 10 in. centre to centre. There was a 9-in. -box, and 5½-in. width of crank-pin instead of the ordinary 4 in. had got plenty of surface for the connecting-rod and cross-head, there was plenty of room to get up and examine or clean the ine-motion. The reversing shaft was a hollow casting of cast . The curved segments forming the slides for the valve-motion, 19, were turned up in the lathe in a circle of the proper radius, then cut off in sections of the required length; they were made ild steel and afterwards case-hardened. For oiling the valve slide-ks the oil-cups were carried on the top of the slides, Fig. 19, so that could be oiled while the engine was running at full speed. All working and wearing parts were circular bushes of hard phosphor-ze; and any of them could be removed by slacking back the oil-which was used for locking in the bush. The oil-cup entering the bush, as shown in Fig. 19, prevented the bush from revolving; by simply slacking back the oil-cup, the bushes could be oved. The coupling rods were bushed on the same method of ing in the bronze bushes by the oil-cups; and the oil-cups were selves locked in in a simple way by a bit of wire.

There was another thing in this locomotive which Mr. Joy's e-motion had enabled him to do. There were only two cotters, e for coupling the piston-rods to the cross-heads. Having that a width of crank-pin to work upon, instead of putting in an nary cotter in the large end of the connecting-rod, Fig. 20, e 62, he had put in a circular taper pin through the block B for ling in the brasses; so that, in disconnecting the engine, all that to be done was to take off the bottom nuts of this taper pin, ten up the upper nut half a turn, and the pin was free to out.

There was also another advantage that was obtained, namely in ightening up and slacking of the connecting-rod brasses. Instead ving the edge of a cotter bearing against the brass, which was

other deviations which he had made in th
ordinary practice, though they did not directly
of valve-motion. One was, doing away with t
rings in the fire-box, and using a water bottom
Fig. 16, Plate 61, thus giving more room
contraction. The fire-hole door was also arran
and a similar opening was placed in the botto
removing the ashes at any time, a sliding door
it, worked from the footplate. A mouthpiece w
for the admission of air under the fire-bars, as
whole breadth of the fire-box; and the tube-pla
or the fire-box repaired, without having to take
remove the water bottom. The damper was ma
so as to deflect the air towards the middle of the

The footplates in all the North Western eng
one standard width over all, as shown in the c
Plate 63; making it worth while to cut rolls
and so economise both labour and materials in the
man-hole lid and the dome cover were also ma
plate, stamped up under the steam-hammer in th
dies, to bring it to the finished shape.

It was an important point for engineers t
some uniform dimensions could not be adopt
engines, in the same way that Sir Joseph Whit

found to be any evil arising from the slightly winding position of the crank-axle, whenever by the action of the springs at the ends of the axle it was allowed to deviate from its true horizontal position. Did this throw anything of a twist upon the connecting-rod or bushes?

Mr. Webb replied there had not been any difficulty from that cause, owing to the arrangements made for allowing ample play; the connecting-rod bushes had $\frac{1}{16}$ in. side play, and the brasses were just eased out at top and bottom, which was enough to provide for all torsional movements due to the vertical play of the axle ends.

Mr. J. H. Kitson said that, having been concerned in the working of a steam tramcar for some years, it had become necessary to him to get rid of eccentrics in some way; and this could be done in several different ways. His arrangement, shown in Fig. 30, Plate 67, was simply a modification of the Walschaert gear, Fig. 38, Plate 69; but the eccentric used in that gear was here got rid of altogether, by deriving motion from the coupling-rod C through a link B, the upper end of which was attached to an arm A on the ordinary curved and slotted expansion-link E. A rocking motion was thus imparted to the link E about its fixed centre; and the rod from the link slide-block being attached to the valve-lever D a little below the valve-rod pin G, while the lower extremity of the lever D was linked to the piston-rod cross-head J, the resultant motion imparted to the valve was a combination of that communicated from the coupling-rod C through the expansion-link E, with that received from the cross-head. In the earlier half of each stroke these two movements were acting in conjunction, and in the latter half in opposition, besides varying in their relative efficiencies throughout the stroke: the slide-valve thereby received a rapid travel at each end of the piston stroke, with a long dwell during the middle of the stroke. By this arrangement, on the principle of taking from the coupling-rod a motion at right angles to that from the cross-head, the same result exactly was obtained as in Mr. Joy's or Mr. Marshall's gear, namely a perfect distribution of steam with a perfect lead; and the very

to be prepared for everything.

Mr. James Humphreys said that, from his
with Mr. Joy, he had had his valve-gear before
and had enquired very carefully into all its
the probability or otherwise of its complete s
hesitation in stating his opinion that it was as
obtaining the cut-off in steam engines, as coul
There could be no doubt, he thought, that fo
would be difficult to obtain a more perfect arra
Mr. Joy. Of course his own particular business
engine; and the advantage of Mr. Joy's system
paramount importance in the case of the marine
types of engine, particularly the locomotive, wh
high pressure was used in a single cylinder, an
very even cut-off in the forward and backward st
importance. Mr. Joy's system might also be ver
to rolling-mill engines, cotton-mill engines, an
that type, where great uniformity of power in th
desideratum.

In the case of the marine engine, it was
comparative cost of the old link-motion and of M
had had the details very carefully considered in
having to apply the system, as he hoped they wo

valve-gear to the connecting-rod than there was in attaching the connecting-rod itself to the crank-pin. After having got all the details as satisfactory as those of the best link-motion, they compared the two, and found that the cost was decidedly less in the case of Mr. Joy's gear, and that there were also a number of advantages which would accrue from its use, such as the better disposition of the valves. There could be no doubt that where the valves could be readily worked from the front of the engine, it was more advantageous in a steamship than if they were placed between the pair of engines, because of course in the latter case they were somewhat less accessible.

Having thus made a careful analysis of the two gears, they were quite disposed to make an experiment on a marine-engine; but of course the builders were not the only people to be consulted in matters of that kind; and shipowners naturally, and he supposed rightly, had great hesitation in adopting any innovations, because in so many instances any deviation from the old plan had been followed by little difficulties, which had not been foreseen. The shipowners naturally had to exercise the greatest possible amount of caution, lest some little hitch should arise in the middle of the ocean, a thousand miles away from everywhere; and they much preferred therefore leaving experiments to some one else than themselves. That was the reason why Mr. Joy's gear had not yet been applied to any of the engines built at the Barrow Shipbuilding Works; but so far as he was personally concerned he should have no hesitation in applying it with the most confident expectation of success. With regard to the question of the wearing, he thought if the bearing surfaces were well considered, there was no reason to apprehend any difficulty on that point. To his mind Mr. Joy's gear would fulfil its functions with a less amount of friction than any other gear he had ever seen.

Mr. WILLIAM BOYD said Mr. Joy had been singularly fortunate in having the powerful advocacy of Mr. Webb, and in having a practical illustration of his gear so prominently brought before the members of the Institution. He was sure that all of them who had

seen the locomotive with this gear on the previous day must have been very much gratified with the way in which the gear was worked, and with the exact movements of the various parts. It was however especially in reference to marine engines that he desired to say a few words. In the first place he had to differ from his friend Mr. Humphrys, since he considered the equal distribution of the steam in the cylinder during the up-stroke and the down-stroke was as important in the marine engine as it was in the locomotive or in any other sort of engine. Now Mr. Joy's gear appeared to him to be theoretically perfect; and it was only in regard to its practical application that any remarks could properly be made.

There were one or two considerations entering into the adoption of gear of that sort in marine engines, which were perhaps different from those that related to its adaptation to a locomotive. Mr. Webb had described the facilities with which he could take up the parts of the gear, so as to adjust the wear and tear. In the case of a marine engine however, it might be at sea twenty, thirty, or forty days, and then any adjustment was a much more difficult task; and any multiplication of the various parts requiring adjustment ought not, he thought, to be lightly entered into. Mr. Joy took his first motion for the gear from the connecting-rod. Now that connecting-rod was suspended between two points, being attached to the lower end of the piston-rod and to the crank-pin; and on both those points during a long voyage there was very serious wear. One of the problems before marine engineers was to provide a metal which should reduce that wear to a minimum. Phosphor-bronze, white metal, and all sorts of things were in use. It appeared to him therefore, with all deference to Mr. Joy, that he had made a mistake in taking the first motion from a part which was liable to so much wear, and required such constant adjustment.

With regard to the two parts of the motion, namely the levers or links B and C, Fig. 4, Plate 58, it was remarkable to notice the unsteady motion on the model now exhibited; and even at the moderate speed of marine engines—60 or 70 revolutions per minute—the unsteady or "wobbling" motion of those levers B and C must be serious. He thought it worthy of consideration whether, considering

rare occasions when the backward gear was used, it might not be risable to avoid those two levers, and to couple the lever E rectly to the connecting-rod, as suggested by Mr. Joy in his paper.

There was another point to which he ventured to take considerable ception. The sliding motion of the block in the slot J would, he hought, be liable to give trouble on long voyages, and it would be mpossible to adjust it. It was of course known that the designer of a link-motion always arranged his rods and gear in such a way that the points of the eccentric-rods came in a direct line if possible with the valve-rod itself, so that the sliding motion of the block within the link when working was reduced to a minimum. It was the motion of the block in the link that was most difficult to manage, so as to take up the wear consequent upon it; and good gear was usually designed so as to reduce that sliding motion to a minimum. In the present case he thought it was carried to a maximum.

In reference to Mr. Marshall's gear, he had had the pleasure of seeing it at work, and knew that it was adopted in several boats which Mr. Marshall had constructed, amongst others some steam turret-vessels running 16 knots an hour. The objection to the wear of the eccentric in the strap he thought was exaggerated. The eccentric had done good service in the past, and he thought they were perhaps a little in a hurry to condemn it as untrustworthy and objectionable. For his own part he preferred the regular, continuous, circular motion of the eccentric in the strap to the fore and aft motion of the point D, Fig. 4, by which in Mr. Joy's gear motion was derived from the connecting-rod of the engine.

Mr. John Robinson agreed very much in the observations just made by Mr. Boyd. It seemed to him there was a difficulty in the motion shown in Fig. 4, Plate 58, from the immense amount of wear which was sure to come on the block sliding in the slot J. He knew how difficult it was in the ordinary valve-motion of a locomotive to prevent that wear and tear; and, so far as he understood it, he thought this prevention would be more difficult in the case shown in Fig. 4 than in the best examples of the link-motion. The other parts were very simple, and commended themselves very much to

manufacturers of locomotive engines, because they could be produced, as Mr. Webb had shown, without smiths' hammers or fitters' tools: everything could be done by machine-work. On the other hand, he did not like increasing the number of pins around which there was simply an oscillating motion. Such a motion always gave trouble. It was not a matter of difficulty perhaps for locomotive engineers, because it was easy to take up the wear; but in the case of long transatlantic or trans-tropical voyages, difficulties might arise. Theoretically he thought Mr. Joy had succeeded most admirably; and he had no doubt that, with such an excellent precursor as Mr. Webb, locomotive engineers would find out how to get over any practical difficulties which might arise from the adoption of this motion.

Mr. ARTHUR PAGET observed that Mr. Boyd and Mr. Robinson had taken exception to the large amount of travel of the block in the slot. He should like to ask them whether it had occurred to them to compare the amount of travel of the eccentric in its strap with the travel of the block in the slot.

Mr. BOYD said he had explained that the motion of the eccentric in its strap was a perfectly different motion from the sliding motion of the block in the link. One was a continuous circular motion: the other a reciprocating sliding motion; and his own view was that he should prefer the eccentric.

Mr. WEBB asked leave to point out that Mr. Boyd had mentioned as the great difficulty in the case of an Atlantic voyage, the taking of the wear in the connecting-rod end; and that motion was a circular motion round the crank-pin. Now in an ordinary locomotive each of the four eccentrics travelled in its strap about 4 feet per revolution, giving about 16 feet in all for each revolution of the engine. He thought that any one riding on a locomotive with 6 ft. 6 in. wheels, and going 60 miles an hour, would wonder how it was that the link-motion lasted a mile. Nevertheless engineers would all be satisfied with the link-motion, if they could

get with it what they wanted to get in the locomotive, namely larger bearing surfaces, so as to keep the engines out of the repairing shop. In some of the London and North Western engines, he had been able to get these larger bearing surfaces; and one engine last year had run 57,000 miles in 52 weeks—a very different result from what they had been in the habit of getting before. He certainly should not be contented with that engine if it would not keep out of the shop for two years; and such a result in regard to mileage he thought would compare with the longest marine voyage that could be made. The vertical motion in the slides in Mr. Joy's gear was 8 in. each way, or 16 in. for each revolution of the engine, and there was one of these blocks for each side; so that the total reciprocating motion in these two slides was only 2 ft. 8 in. for each revolution of the engine, very considerably less than with the eccentrics.

With regard to the number of pins, anybody could count the number of those that had any work to do, which he thought would compare favourably with any link motion, especially if a weigh-bar had to be introduced in the latter, on account of the large cylinders.

Mr. Jeremiah Head said at first sight Mr. Joy's design recalled to his mind the old box-link, which was used about thirty years ago in the Great Western locomotives, and the action of which was described in Clark's "Railway Machinery." In that case (Figs. 36 and 37, Plate 68), the curve of the link A was drawn to the radius of the valve-rod link; and in the same way as in Mr. Joy's gear, the block could be moved up and down in the link, when in mid-gear, without altering the lead of the valve. The distribution in fact was about as perfect as Mr. Joy's. For some reason or other —principally, he believed, because of the somewhat complicated construction of those links—they were abandoned in favour of the ordinary open links, the curve of which was drawn from the centre of the axle, thus presenting their curvature in the opposite direction to the old box-link.

There seemed however to be an essential difference between the gear exhibited and the box-link gear. In the latter case it was the eccentrics pushing the link backwards and forwards that did the real

the lever pulling or pushing very much athwa
having great resistance to overcome; and t
no doubt lead to wear. With the old box-l
inclined at the same unfavourable angles at cert
eccentrics were pushing the whole of it bo
forwards, the oblique thrust of the block in t
felt in the working of the link; but if the drive
engine while the link was in that inclined posi
hard work indeed to do so.

It had been stated in the discussion that the
might give trouble in a marine engine in the co
partly on account of the wear; but in fairness t
be noticed that those were parts very easily
He saw nothing whatever to prevent such a s
those slotted discs and the block in it being t
every voyage. If there was any undue wear, th
easily replaced; but of course the engine woul
for doing so.

A good deal had been said in the discuss
Some engineers thought them disadvantageous
considered them quite harmless. He was i
mechanic would put in an eccentric, in order
from circular motion, if he could do without
comparatively harmless where they were small

off, whereas the front half, which was the only part that did the work, was considerably worn; and in some cases the eccentric had to be taken out and re-turned, in order to restore the full throw. Then again, when an eccentric after wear got somewhat slack, it was always open at the back part, though touching at the front. That offered a large space for dust, grit &c. to get in; and this was immediately carried round, and helped to wear the front part still more. Therefore he thought that eccentrics were things to be used only as a last resource. That was perhaps the chief disadvantage of Mr. Marshall's motion compared with Mr. Joy's; the former still retained one eccentric for each engine.

In marine engines it frequently happened that three eccentrics were used to each engine, two being used for one end of the link and one for the other, making six altogether, all encumbering the shaft, and making the bearings almost inaccessible. It had been pointed out by Mr. Boyd that the two ends of the connecting-rod often required adjustment to some extent, between the beginning and the end of a voyage, and might therefore be very variable points. It had not been noticed that the motion-bars on the forward side were apt to wear, which would tend to aggravate any error in the same direction; but he did not quite see why the link E, Fig. 4, Plate 58, should not be made adjustable in length. If it was a round rod bellied out in the middle, with a left-and-right screw, its length might easily be adjusted to compensate for wear in the connecting-rod ends. He enquired whether he was correct in thinking that, when the sliding-block was in mid-gear, supposing the engine was running and had a little way upon her, there was enough admission to keep her running, whichever way she was going: so that the engineer would not be able to stop, by the reversing handle alone, if the load were light, unless he pushed the slot-disc over to put the steam on the other side of the piston.

Engineers had all been accustomed to look upon the link-motion with a sort of veneration, as one of the great improvements in the locomotive, which had rendered the name of Mr. Howe famous, and which was supposed to be a complete solution of the question of valve-gears. They had hardly ever thought of disturbing that idea,

or that it would be disturbed, as it was considered to be one of
points that were settled for ever. Mr. Joy however had show
it might be improved upon; and with regard to tramway en
Mr. Kitson had pointed out that, with the dust and dirt they
encounter, eccentrics and eccentric straps were absolutely inadmi
Mr. Joy therefore deserved great credit for having brought fo
his new valve-gear; and his paper was one most suitabl
the Institution.

Dr. C. W. SIEMENS said that, listening to the very excellent
which had been brought before them, and to the observations
speakers who had taken part in the discussion, one result seen
his mind to be quite certain, namely that the link-motion
doomed. He must say he did not feel the same regret on that
which appeared to animate Mr. Head. The link-motion ha
doubt been a way out of a difficulty; but it was correct only
very narrow limits; and the moment those limits were excee
did not produce the expansive action desired. A motion had
been brought before them which challenged comparison with the
expansive gear that could be mentioned. There was a clean cu
the steam was put on at once in ample quantity, and the exhaust
was opened promptly at the right time. There was also the m
of adjusting the action so as to make the up-stroke and the d
stroke perfectly alike, which, as they all knew, was not the case
the link-motion. And, as Mr. Webb had beautifully illustrated
his locomotive, the new gear had the advantage of giving a l
useful space on the main shaft for increasing the length of
bearings. These were very important advantages, which Mr.
might claim for his motion. But they had also been put in posses
of two other motions, which seemed to be as perfect as Mr. Jo
Still they need not regret that result. There were points of differe
between the gears, though they all aimed at the same result, a
perfect cut-off and a perfect mode of reversing the engine.
object was achieved by different mechanical details, all of which
considered were superior, both theoretically and practically, to the
link-motion.

e criticism offered by Mr. Boyd, in regard to a portion of notion, he thoroughly agreed. The slotted disc, which into a different angular position, with the slide-block and down in the slot, was not he thought a desirable he would recommend Mr. Joy to do away with it. He had actually been done away with in the arrangement ate 59. All the friction was there reduced to the friction which must be preferable to friction of sliding surfaces. xception Mr. Joy's motion appeared to him perfect, and ould no doubt receive the most earnest attention of ngineers.

Reynolds had not intended to say anything on the r one expression used by the author, that the present lped to show the advantage of the patent laws. That el there was some danger of being excluded by patent the use of inventions, on account on what appeared to ere modifications of detail. He wished success to both d Mr. Marshall; but when such small details as the of Brown's sling for the slide of Hackworth's gear subject of a separate patent, this danger seemed to . Fig. 35, Plate 68, showed an arrangement which he had ack proposed to use for a very large steamer, and which he ght be considered as the normal idea of this class of e inaccuracy due to the arc made by the ends of the eliminated by what would be a parallel motion of the d, if it were not for the side motion of the connecting-rod; herefore correctly reproduced.

motion, to which some allusion should be made, was Fig. 40, Plate 69. Since this was first introduced, it ubject of interest with all engaged in locomotives; but fect, being rather adapted for each motion to work the e than to work its own. When Hackworth's gear was all difficulty vanished, because by adding the slide-block at right angles to the connecting-rod became properly , and the whole thing was very easy. Then the question

whether Mr. Charles Brown's sling or the ordinary slide was
was not of much importance in regard to the principle.

Mr. F. C. MARSHALL asked to be allowed to say one word in refe
to the sliding motion. There was only one thing that inter
with the success of the Hackworth motion, Fig. 31, Plate 6
which his own motion and Mr. Joy's were modifications: what
hindered its general success had been the sliding motion, w
Mr. Joy had now introduced into his gear. With regard to
eccentric in his own design, he certainly could not feel any g
horror at it, and he believed that, as long as engineers used cr
shafts, they would not be able altogether to dispense with eccent
As to the adjustment of the connecting-rod ends, those who had b
at sea ten or twenty days would know that connecting-rods, e
when made of the best metal, got very serious knocks, and
these were communicated to everything connected with them,
necessarily to the valve-rods which Mr. Joy had introduced. A
the wear on the connecting-rod pin, the pin as introduced into
Joy's gear was somewhat similar to that used in Mr. Charles Bro
tramway engine, upon which a paper had been read before
Institution in January 1880. That engine was now running
Newcastle, and the only difficulty they had with it was with the
on the connecting-rod.

The PRESIDENT said the subject of slide-motions had bee
favourite one with him since he was an apprentice. In olden t
he had seen engines with tappet motions, but they were
satisfactory. With the eccentric however everything was tho
to be quite right. Capt. Ericsson had tried several forms of mot
when connected with the late Mr. John Braithwaite in business:
favourite form was a slot fixed on the end of a rocking weigh-
so as to form a T with it; the shaft was worked by an eccentric
the end of a connecting-rod from the slide-rod was movable in
slot, so that the motion of the slide was reversed by moving
connecting-rod end from one side of the axis to the other.
plan of course could not be arranged to give lead both ways, th

the engine could well be reversed whilst in motion, without any danger of the end of an eccentric-rod missing its pin or getting adrift. He (the President) then schemed the plan of using a *short* eccentric-rod, and moving it from a pin fixed to a lever on one side of the weigh-shaft to a pin fixed to a lever on the other side of the weigh-shaft, thus reversing, and obtaining a certain fixed lead each way, owing to the different angle at which the motion was taken off the eccentric.

The problem seemed to be that of taking advantage in some way of the up and down motion of the piston-rod for lead, and also of the side motion of the connecting-rod, or of the eccentric, so as to give the proper action for the travel of the slide. He had tried that himself many years ago, but had failed. He would not have a *sliding block* in a slot; and he fancied that had been the reason why he had failed to combine the two motions. It had since been done much better by Mr. Joy, Mr. C. Brown, Mr. Marshall, Mr. Kitson, and Mr. Walschaert. Hackworth's gear, Figs. 31 to 34, Plate 68, was no doubt the origin of all these. With Hawthorn's gear, Fig. 40, Plate 69, the vibration of the locomotive springs caused great shocks, and the gear had knocked itself to pieces. This was in consequence of the connection between the valve-lever and the pin in the main connecting-rod being made by a large and heavy frame, with a long slot in it the full length of the stroke, instead of by a light connecting-rod. In the way in which Mr. Joy had arranged it, it would be observed there were two plans. One was that of a slide which was constantly in motion within a slot, in contradistinction to the small motion of the slide-block in the link-motion. These were very different things: one was a constant wear, and the other a small local wear at either end of the link. This was avoided in some marine engines, where the link was thrown right over and rested against the block, so that the block did not move in it except when reversing. In the locomotive there was a little motion of the slide-block in the link, which caused the end of the link to wear very much, and it was not long before the size of the whole link had to be increased. The other plan of Mr. Joy's seemed entirely to cure that evil; it was shown in the model exhibited. The

[illegible] gave the inclined mo[illegible] [illegible]; there was no slot, and the ce[illegible] [illegible] with the link. Then t[illegible] [illegible] attachment to the connect[illegible] [illegible] space was thereby al[illegible] [illegible] therefore so safely get at [illegible] connecting-rod end, which [illegible] He thought that was objection[illegible] [illegible] seemed really to be avoided. [illegible] Mr. Charles Brown's tramway eng[illegible] [illegible] seemed to have five different moti[illegible] [illegible] motion, and all of which [illegible] [illegible] another.

[illegible] from a practical point of vi[illegible] [illegible] was that he could get am[illegible] [illegible]: and that was a good thi[illegible] [illegible] would give that one advantage, [illegible] [illegible] was only as good as th[illegible] [illegible] it was better. The motio[illegible] [illegible] and in the exhaust, althoug[illegible] [illegible] a small amount of compressio[illegible] [illegible] was due to the early exhaust; and [illegible] amount of admission of steam, [illegible] Mr. Webb's indicator diagram [illegible] means the cylinder was got clear [illegible] was a very good back or exhaust line, and a [illegible] of compression. That was done by cutting out the inside of the slide. It was not universally known that by cutting out the inside of the slide the compression was materially reduced, the bottom line of the indicator diagram was improved, and only a trifle was lost at the end of the stroke from the earlier exhaust. So again in Mr. Marshall's diagrams, which were excellent, a little of the pressure at the end of the stroke was lost by the earlier exhaust; but what was there lost was far more than made up in the improvement of the bottom line in the indicator diagram, and there was a very small compression.

oy, in reply, said he feared the paper had already occupied n its fair share of the time of the meeting, and he would endeavour to be as concise in his answers as possible; but iestion were thus left unanswered, it was not because he had er for it, as he was fully prepared for every criticism which n brought forward. He was partially prepared, but only , for the observations made by Mr. Marshall, who had kindly im a copy of his indicator diagrams, but not in time for a f them; they were certainly very perfect. Mr. Marshall's wever went only half way towards improving the link gear, ting the engine into as short and smart a form as it ought to . In that gear the valves were put in at an angle; and that element which he himself maintained was wrong, and would ie engine costly. He had seen the engines of this type, built hardson at Hartlepool, and understood that they were some to build from that cause. Only one of the eccentrics noved, and the other was left, still cumbering the crank-shaft. rangement also was not well suited for any other class of than that for which it was shown; and for locomotives and ss of engines it was entirely unsuitable, as was Hackworth's: iis own gear described in the paper was designed to suit every condition into which a steam engine could be put, allowing y case a better and more compact arrangement than could be d with the link motion.

ain, the engine-room was not shortened; and he maintained ere was an advantage in shortening the engine and the engine- The navy was now pressing them to put their engines into allest possible space. As for the condenser being the limit of gth of the engine, that was not so: if the condenser was too t was easy to shorten it and widen it; there was plenty of or that on board ship in the direction of the width of the where there was always plenty of vacant space. With to the number of parts, he might remind them that in Mr. ill's gear there was an eccentric running upon a shaft, as four little pins in his own gear; and it should be remembered links B C, Fig. 4, Plate 58, were only doing about one-sixth work of the eccentrics, as Mr. Webb had shown. With regard

to the port, he confessed he could not see how Mr. Marshall perfect diagram, except by a special device, to which he woul presently. The long valve-rod link, which had been spo as an advantage, he maintained must be a disadvantage, b the arc in which it vibrated was not equal to that in whi eccentric-rod end vibrated; and these arcs crossing each othe produce error. In his own gear these two arcs were made equ so corrected each other. There was also an uncorrected arc f by the obliquity or vibration of the eccentric rod acting as a and this would produce unequal vibration of its suspended en therefore inequality in the opening of the ports: the former err believed, having the same tendency. From the drawing howev gathered that these errors were corrected by the valve having a lip at the top end and a port formed in it, Fig. 25, Plate 6 making a double port for admission at the top end of the valve, a single port at the bottom; and this appeared really to be Marshall's point of improvement, and not the gear at all. regard to the further remark that all these valve-motions modifications of Hackworth's old gear, he could not agree tha own was so, as it had arisen out of an endeavour to design a v motion taken from the air-pump lever and combined with a trans action from the vibration of the connecting-rod; and in this for had drawn it out at first. In its present form the link or lev Figs. 7 and 8, Plate 59, now took the place of the air-pump leve

He was much obliged to Mr. Webb for the very prompt an thought, far-seeing way in which he had taken up the idea, fo exhaustive analysis to which he had subjected it, and finally fo very perfect and practical way in which he had carried it out. thought that this was perfectly in accordance with the spirit o Address of the President, where he said that if they were to forcigners out of the market, Englishmen ought to take hold of things, sift them to the bottom, and, if they were good, carry out. This was precisely what Mr. Webb had done; and it beh all English engineers to follow the same bold and prescient p if they were to hold their own as the leading engineers of the w

Mr. Humphrys had gone into the matter most thoroughly could therefore speak with authority; he had also told off the

talent of the Barrow Shipbuilding company's staff to analyse and then work out the question. After he (Mr. Joy) had given all the ideas he could to the draughtsman, the designs were put in hand and carried out without any interference on his own part; therefore the result as stated by Mr. Humphrys might be relied on and accepted as satisfactory. He regretted however that he must differ from Mr. Humphrys when he said that he did not attach so much importance to the exact and equal distribution of steam for compound marine engines, but that it was very good for locomotives; and so it was. But whatever was good for a locomotive, with high-pressure steam, was good also for a marine engine, which was now approaching the higher pressure of the locomotive. If perfection of distribution were good for the one, then it should also be good for the other, especially when obtainable at even a lower cost than the present tolerated imperfection. Marine engines were already working up to pressures of 90 lbs., and he had been asked in London about some ships in which 100 lbs. pressure would be required. He was quite certain they would reach 150 lbs. before long. He fully agreed with Mr. Humphrys however that the greatest difficulty in the way of the introduction of improvements lay in the conservatism of the shipowners and their advisers, who were usually cautious to a fault. No doubt this caution often saved them from making mistakes; but it often delayed the advance of improvement.

A great deal of what Mr. Boyd had said had been answered by Mr. Webb and by Mr. Humphrys; but there was one point which Mr. Boyd had made a great deal of, namely the plunging and knocking of the connecting-rod at sea. He had been at sea himself, and knew all about that. It was true that he took his point of force from the connecting-rod, but in the first place he took it half way along the connecting-rod, and in the second place he took it through the link B, Figs. 7 and 8, Plate 59, and at each step by reduced leverages, thus reducing the knock or looseness that might have been imparted by the connecting-rod. By attaching the lever E to the link B at the point D, the distance travelled by the valve-rod pin was only one-tenth of the distance travelled by the pin D. If there was a quarter of an inch knock in the connecting-rod (an amount impossible to be allowed), and so a quarter of an inch

looseness at the pin D, there would be only one-tenth as m
the other end of the lever E, or $\frac{1}{10}$ in. at the valve, an
inappreciable amount. The practice of locomotive engineers
put interchangeable bushes and pins in all the wearing parts.
were out of the control of the workmen; and when any
interchangeable bushes or pins failed or gave way, they had n
to set a man fitting two brasses and getting them exactly ali
they took out one pin or bush and put in another. It ha
stated by Mr. Webb that a locomotive engine would run ei
months or two years without being touched; and yet it wa
that in the course of the ten days required to cross the A
a connecting-rod must be so much knocked about as to interfer
the correctness of this valve-motion. With regard to the act
the compensating links B and C, and the "wobbling" of tha
of the gear, spoken of by Mr. Boyd, that action was much wo
the ordinary air-pump lever gear, where the coupling links ha
vibrations for every revolution; while in this motion the vib
and radius links B and C had only one movement for
revolution, and indeed during half the revolution the radius-r
was absolutely at rest, moving only when it had to correct the
of the arc in the return stroke of the connecting-rod.

Mr. Robinson was one of their highest authorities; but he
not help differing from him in his idea that there would be a g
deal of wear and tear from the sliding of the block in the curved
J, Fig. 4, Plate 58. That there would not be that wear and tear
been pretty clearly proved by Mr. Webb, who had had his en
tested for a breakdown to see what part would fail first; but he c
not hear that anything had failed as yet, and the workmen had
that they had never had a bearing hot, or a pin to take out. How
he only proposed to introduce this slot where it would suit
arrangement best—say for locomotives, traction-engines, st
ploughs, and so on, and where simplicity and cheapness were of
first importance. The moment he came to a large engine, he pu
the gear shown in Figs. 7 and 8, and had a double radius-linl
one on each side. Then all the motion was in the same plane; t
were equal bearings and equal strains on both sides of the connect
rod, and all the parts were got in a straight line. That could no

done with an eccentric and link gear, because it would be necessary to put two eccentrics in the same place, which was impossible.

With regard to the wear upon the sliding block however, he would draw attention to this fact: that even if it were considerable, it was not at all equal, as Mr. Webb had shown, to the enormous wear upon the eccentrics, which had four times the area exposed to wear. He could give as much bearing surface in the slot, without making it unsightly, as there was upon the slide-bars of the piston-rod cross-head. And there was never any trouble with slide-bars properly constructed and properly attended to, and no one ever dreamed of carrying a cross-head on radius-links; yet the slide-bars had enormously more work to do than the inclined slot in this motion, and as they stood wear so should this. Further, for this part of the motion there was an exact precedent, which had stood the test of years of working, in the transmission of the power for working the valves of oscillating marine engines, which were often of very large size; there the action of the eccentrics was transmitted through a sliding frame having curved slots, in which slid the blocks hung on the ends of the levers working the valves: the only difference between the two cases was that for the above gear all the sliding blocks were carried on overhung pins, while in his own gear the sliding block was double-borne by a pin at each side.

With regard to the facility with which the engine could be reversed, he had found some years ago, when he was a locomotive superintendent, that he could not himself reverse an 18-in. cylinder engine; but reversing the new 18-in. engine was as easy as possible. The reversing of a link-gear engine was done by drawing the link-block down against the friction in the link; and when the angle was unfavourable, this was considerable; but in the present case the only force required was that necessary to pull over the lever and draw the valve along in a straight line.

Mr. Reynolds, after he had been shown the present plan, had sent him copies of his own, and said that a firm of engineers had suggested it should be used; but it had not been used by Mr. Reynolds himself or by others; and in that case, as the design had not been introduced and brought out, it was open to any one else to introduce it afterwards. In the paper it was stated that the first drawing of his

wearing surfaces and great length of stroke.
why Hackworth's gear, Figs. 31 to 34, Plate 6
been that it had only 5-in. or 6-in. stroke
therefore a very excessive angle to work a
angle as in his own gear: so that it w
excessively up-hill. The difficulty was that
opening the port was given by that incline, w
length, and therefore it had to be set at a
corresponding angle in his own gear for a ful
but he believed Mr. Hackworth's had been a
to the wear in the slot, it would be no more
present link-block. But in his own gear it
from end to end; so that when it got to kno
even all over, and a new block would reme
gear the wear was uneven, all at one place
so that there was often a little hollow in the
and this necessitated reducing the whole su
Head had pointed out quite correctly tha
sliding block would be pulled or pushed som
which would no doubt lead to wear. That
equalised by putting in new blocks.

Before he concluded he wished to thank

ON A STANDARD GAUGE FOR HIGH PRESSURES.

BY M. GEORGE MARIÉ, OF PARIS.

Machines worked by water at a high pressure have recently come into extensive use. The admirable hydraulic cranes of Sir William Armstrong, used in goods stations and elsewhere, are familiar to everybody. Mr. Tweddell also employs a high pressure of water in his well-known hydraulic riveters and other tools. The naval departments of several countries have built small torpedo boats, running under the sea, and worked by highly-compressed air. Lastly, the use of testing machines becomes more and more general, and these machines generally work with water at high pressure.

Looking to these many applications of water or air, working at a high pressure, it appears very desirable to discover a thoroughly good pressure-gauge or manometer, capable of measuring high pressures with sufficient precision.

Metallic gauges.—The most convenient apparatus for this purpose is undoubtedly the ordinary metallic pressure-gauge; it works fairly well at the lowest and at the highest pressures, say up to 1000 atmospheres if necessary. But this system has a very serious defect: its graduation cannot be fixed by the aid of calculation alone; it is only a comparative instrument, and its graduation must be fixed by comparing it with some other sort of manometer, which can be graduated by calculation.

From 0 to about 30 atmospheres, it is easy to employ for this purpose the open-tube manometer, which gives with the greatest precision the exact measure of the pressure, by the height of the column of mercury which it supports. But when the pressure is higher than 30 atmospheres, it is difficult to arrange an open-tube manometer. Messrs. Cailletet and Amagat however made in 1879 several

instruments of this kind working from 0 to 400 atmosphere the apparatus is very delicate and expensive, and experiment only be made in a mining shaft, because it is necessary to h vertical tube 200 or 300 yards in length, filled with mercury. apparatus may be employed for scientific purposes, but it is practical instrument for mechanical use.

Standard gauges, various types.—The Lyons Railway Com has for several years been seeking for a standard gauge, g simply the exact measure of high pressures, and at the same convenient for the graduation of metallic gauges; the me of graduation for this purpose must be simple and rapid, bec the gauges ought often to be compared with the standard g Many types of standard gauge have been tried without success.

Compressed-air manometers are too delicate in construction, their indications are not reliable at high pressures, because assume that the volume of air decreases proportionately to increase of pressure, whereas the last experiments of M. Cail show that this law is far from being true at high press Gauges with differential pistons have also been tried; but these the resistance and friction of the membranes always pro important errors. Both these types have been employed by makers of metallic gauges; but their results have always b unsatisfactory, as is easily seen by comparing the graduatio metallic gauges coming from different makers in England, Ame Germany, and France. It will be found that their indications quite different at high pressures.

The Lyons Company has tried another system, which has often employed by gauge makers. In this the graduation of metallic gauge is made by the aid of a loaded valve, Fig. 1, Plat similar to the safety-valve of a boiler. The water reaches the u side of the valve through a pipe A, which is in communication the metallic gauge to be graduated. If the pressure of the w increases slowly, the valve will open when the pressure equals total load on the valve, divided by the area on which the water At that moment, the position of the needle of the metallic gau noted; and this gives the graduation for that particular pressu

that particular apparatus. If several experiments are made with different weights on the valve, a complete graduation of the metallic gauge can theoretically be obtained.

In practice, the results of this system are very bad. If several trials are made with the same weight W on the valve, the valve will open at different positions of the needle on the metallic gauge. This result can be easily explained. When the water is under no pressure, the weight W exerts a certain pressure on the edge of the valve: let S be the area of the valve out to out, s the area of the opening; then the metallic surface in contact at the edge of the valve-seat is S — s. In practice, with high pressures, S must be almost double of s, otherwise the edge of the valve-seat will be broken, when the valve falls on its seat. In any case it is necessary to use a very good and hard metal for the valve and for its seat. Now as the pressure below the valve increases, and when the valve is not far from being lifted, the pressure on the surface in contact becomes very small; then a slight leakage of water generally takes place under the valve, and the water begins to exert its pressure on a surface larger than the area s of the opening. At that moment the surface under the action of the water is somewhere between the two areas s and S; but, as already mentioned, one of these must be about twice as large as the other; thus the possible error in the measurement is not far from 100 per cent.

With lower pressures the error would be much smaller; but in that case the use of the valve is needless, because open-tube manometers can be employed.

The Lyons Company tried another valve of a conical form, Fig. 2, Plate 70, but found it no better than the preceding one. A spherical alve has also been tried, Fig. 3, the sphere being made of very ard agate, and the seat of hard steel; but the results were quite as ad as in the other instances.

Description of the Author's system.—The Author has now given brief description of the best systems which have been tried for the aduation of metallic gauges. The open-tube manometer is the ly one giving an exact measure of pressure, and we have seen

that its application is not practical with high pressures. . the end of 1879 the author made trial of a new system whic given the best results; it consists in the use of a perfectly cylin piston C of hard steel, moving in a bore also perfectly cylind within a casting B, Fig. 4, Plate 70. The water under pressu access to the under side of the piston through a pipe A; a l opening and another pipe afford communication with the m gauge G, which is to be graduated. The piston C of course ri soon as the pressure of water on its under surface exceed weight with which it is loaded, and the position of the nee that moment gives the graduation of the gauge for that pre as before.

The piston moves in the bore with very slight friction, so that the piston falls by its own weight when there is no pr below it. Nevertheless the leakage is less than 1 cubic centi (0·06 cub. in.) per second, at a pressure of 200 atmosp The upper part of the piston is fixed into a metallic lid D, supports the weight W when the piston is at rest. It is imp to remark that this lid D has not to prevent the leakage of The small drops of water leaking between the piston and the have a *free discharge* under the lid, through the openings E; wi these openings the apparatus would be no better than the ord valves.

It is necessary to lubricate the piston with good oil; the carries off a large part of this oil, but a small quantity stays o metal, and makes the friction less. The piston and casting made of steel as hard as possible, but not hardened. Pract the apparatus works very smoothly, and if the same experim made several times over, the piston always moves exactly wit same position of the needle on the metallic gauge.

This particular instrument has been at work since Dec 1879. The piston has a diameter of 15 millimetres (0·59 in.) it works from 0 to 200 atmospheres. The pressure is give means of an accumulator between 0 and 50 atmospheres, and by

* A piston of the same kind has been long employed for measuri pressure of powder gases in the bore of guns.

of a Thomasset's high-pressure compressor between 50 and 200 atmospheres. The same instrument would work easily at a pressure higher than 200 atmospheres, but there is no machine giving such high pressures in the works of the Lyons Railway.

In practice, instead of a dead weight W, the piston is loaded by a graduated lever on which runs a moving weight, as shown in the general arrangement, Fig. 5, Plate 71. Instead of using the lid D, Fig. 4, the lever itself is supported at its extremity, Fig. 5, and cannot descend lower than its horizontal position; and the piston, being held up in contact with the lever by suspending springs, cannot sink lower into the bore when the water pressure ceases to act upon it. An electric bell gives notice of the lifting of the piston: the pressure of water is increased very slowly, and when the bell rings, the observer has to mark the position of the needle of the metallic gauge at that moment. The whole apparatus has been made in the works of the Lyons Company.

Objections to the Author's system.—Many objections have been urged against the system described. On these the Author has made a complete report, in which their influence is carefully calculated. This report is added in the Appendix; the Author will here give only the results of his calculations, divided under the different sources of error which arise.

1. The pressure of water under the piston is somewhat diminished by the leakage past the piston. This would naturally be looked upon as a very large error, but in reality it is very small; its calculated value is only $\frac{1}{6,500,000}$.

2. The lateral opening to the metallic gauge is made at a point where the water, instead of being in statical equilibrium, has a certain velocity; this produces a proportional error, which is different from No. 1; but its value is only $\frac{1}{1,000,000,000}$.

3. The leakage water exerts a certain amount of friction between the piston and the bore; this friction gives a proportional error, which is smaller than $\frac{1}{143}$.

4. The diameter of the bore has been measured with an instrument accurate to $\frac{1}{20}$ millimetre (0·002 in.); this inaccuracy may give a proportional error of $\frac{1}{142}$.

5. The diameter of the bore alters with the temperature of the water; this may give a proportional error of $\frac{1}{2,500}$.

6. This objection is the most important; it concerns the effect of the metallic friction between the piston and the bore. The Author has already stated that the piston can move in the bore without sensible friction when the water has no pressure; but when the pressure is on, a little dirt may find its way between the piston and the bore, and cause an amount of friction which may be considerable in some cases. This metallic friction is quite different from the friction of the water between the piston and the bore, the value of which is $\frac{1}{143}$, as mentioned in No. 3.

It is impossible to estimate by figures the friction of dirt in such circumstances, but it is easy to eliminate the error arising from this source. In order to eliminate this error the Author makes two measurements for each value of the weight upon the piston. The first of these is made with the pressure increasing. In this case let M, Fig. Plate 71, be the position of the needle when the piston begins to move, the levers being arranged so as to give the piston a very small stroke, say about one millimetre (0·04 in.). Then, after the piston has moved, it remains in its highest position, 1 mm. higher than the lower position from which it started. After a few seconds the flow of water must be stopped by closing a stop-cock in the pipe A. Then the pressure decreases slowly under the influence of the leakage around the piston, and after a few seconds the piston drops. Let N be the position of the needle when the piston drops; then the middle point P, between M and N, is the correct point of graduation. This can be shown as follows. The metallic gauge is supposed to have no friction at all, which is not far from truth in practice. Then it will be seen that the friction of the dirt has a retarding action on the motion of the piston in both directions. Hence if we assume that this friction requires a pressure of p lbs. per sq. in. to overcome it, whether the piston is rising or falling, then the needle will indicate p lbs. more when the piston rises, and p lbs. less when the piston falls, than it would do if this source of error were absent. The difference $2p$ is represented by the distance M N, and, dividing this distance at P, we get the pressure which would be indicated if this friction were

nothing. In practice, unless the water is dirty, the length of MN is smaller than $\frac{1}{100}$ of the total length OM. Sometimes it may be a little larger, but in that case it is better to remove the piston and clean it carefully; the difficulty can be avoided altogether, if the water employed is carefully filtered. The return of the piston is easy to notice, since the electric bell begins to ring when the piston rises, and continues to ring until the piston falls.

Friction of metallic Gauges.—The Author has already remarked that the friction of metallic gauges themselves is generally very small; but, if they are not carefully made, the friction of the needle and other parts may sometimes be considerable. The following is a description of a very simple apparatus for measuring the amount of this friction; it has been designed by the Author, and made in the works of M. Guichard, metallic-gauge manufacturer in Paris. The apparatus, Fig. 6, Plate 71, is a kind of metallic gauge consisting of a pipe coiled in a spiral form: the water passes through an opening A to the centre C of the spiral; the other end B of the spiral is closed, and a needle BD is fixed to it. The section of the pipe is elliptic, as in the ordinary metallic gauges. When the pressure of water increases, the spiral enlarges itself; the centre C cannot move because it is fixed to the board, but the free end B moves, and its motion is multiplied by the needle; this motion is measured on the graduated curve D. Such a gauge can have no friction whatever, because the needle is fixed on the tube itself without any transmission. With this instrument it is easy to measure the friction of a metallic gauge at every point of its graduation. For this purpose both gauges are connected with the compressor; then the pressure of water is increased until the needle of the metallic gauge reaches the desired position P, at which the friction is to be measured. Let q be the corresponding position of the needle of the spiral gauge. Then the pressure is increased somewhat further, and afterwards decreased: let q' be the new position of the needle of the spiral gauge, when the needle of the ordinary gauge has returned to its first position P. Then the friction of the gauge under trial is given by $q - q'$, and the proportional friction is $\frac{q-q'}{q}$. In practice, with a good metallic gauge, $\frac{q-q'}{q}$ is smaller than $\frac{1}{80}$.

Design of the Standard Gauge.—Fig. 5, Plate 71, gives the des the actual apparatus, which has been working since the end of the accuracy of the measurement given with that appara within a limit of error of 1 per cent. less or more.* This is sufficient for engineering practice, but it is easy to obtain a accuracy for purposes of science. The Author has designed apparatus in which the piston is of 25 mm. diam. (1 in.) inst 15 mm.; several alterations also are made in the levers.† apparatus will be constructed at the works of the Lyons Ra the piston will be made of aluminium bronze (10 per aluminium and 90 per cent. copper); and the diameter o bore will be measured to an accuracy of $\frac{1}{100}$ millimetre a works of the French Artillery in Paris. The accuracy o new apparatus will be within $\frac{1}{300}$ or $\frac{1}{400}$, if it is well made. a degree of accuracy is necessary for scientific purposes; bu mechanical practice the accuracy of the Author's existing appa $\frac{1}{100}$, is quite sufficient. It is probable that the Company will machine giving a pressure of water higher than 200 atmosp since the new apparatus will be strong enough to measure atmospheres or more if necessary.

Pumps are very defective appliances for giving the press such experiments, because, with a pump, the needle of the me gauge is in continual vibration. It is much better to empl accumulator or a compressor.

Applications of the system.—The Author believes that the measurement of pressure given by this instrument will find applications in science, and in mechanical engineering. The foll case is especially interesting. Testing machines have now established in many works; but they are somewhat expe machines, consisting generally of a hydraulic piston to giv required force, and of other apparatus to give the measure of force. The Author is of opinion that a great simplification m introduced, if the force be measured simply by multiplyin pressure by the surface of the piston. This would have

* See the Appendix on the sources of error.

† The Author has presented the designs of the new apparatus to the Insti

advantages: firstly it would greatly diminish the cost of testing machines; and secondly it would enable them to be made on a much larger scale, with a pull of a million kilogrammes (2,200,000 lbs.), if necessary. The Author has made many experiments showing that the friction of the leathers is less than $\frac{1}{100}$, when the pressure of water is high, and when the piston is perfectly polished and well greased; then, with good leathers, and with a well graduated metallic gauge, the measure of the force is easy. It may here be observed that the metallic gauges generally in use are too small; they would be better if the flexible tube were larger and stronger; the extent to which the motion must be multiplied would then be smaller, and they would give a much better result.

Again a piston of the same kind may be employed as a safety-valve; the piston should in that case move in a cylinder having lateral openings, the water flowing out through the openings when the piston is raised; the stroke of the piston should also be much longer than in the standard gauge here described. A high-pressure safety-valve of this construction is now in use at the works of the Lyons Company.

The Author may conclude by observing that the first idea of these experiments was suggested to him by the experiments of Captain Galton and Mr. Westinghouse on brake friction at high speeds. In the experimental van then used, the various strains were estimated by measuring the pressure of water in several Richards indicators; but the piston of a Richards indicator has no packing, and the water leaks past it exactly as in the Author's apparatus. The Author will be glad to give the Members of the Institution any further details which may be needed; he will also be glad to show the working of the apparatus to any member visiting Paris. In the Appendix he has given an answer to the objections which have previously been made to the system; and he will do his best to reply to any other objections which may be made by Members of the Institution.*

* Any member of the Institution or English manufacturer is at liberty to make the apparatus, without payment of royalty.

APPENDIX.

ESTIMATE OF ERRORS.

1st. *Error due to the momentum neglected.*

Consider first a section $A_0 B_0$ of the liquid, Fig. 7, Plate 71, so far from the piston that the filaments of liquid are perfectly parallel. Secondly consider another section C_0 D_0 of the annular vein, close to the poin of escape of the water, and in which the filaments are also parallel. Let A_1 B_1 and C_1 D_1 be the positions of these sections respectively at the end of a unit of time. Then the volume between A_0 B_0 and A_1 B_1 must be equal to the volume between C_0 D_0 and C_1 D_1; each being equal to the discharge of water per unit of time.

We have now to apply the principles of dynamics to the body formed by the liquid mass between A_0B_0 and C_0 D_0, and by the loaded piston of weight W. This piston will be in the same position at the end of a unit of time, while the liquid mass will have moved into the position A_1 B_1 C_1 D_1. We assume that the action of the external forces during the unit of time is equal to the loss of momentum in the body under consideration. Hence we have the following equation—

$$\int_0^1 F dt = MV_0 - MV_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\ )$$

where F is the resultant of the exterior forces, M is the mass of the body considered, and V_0 and V_1 are its velocities at the beginning and end of the unit of time.

To determine the forces, let S be the area, at A_0B_0, of the cylinder in which the piston moves, p the actual pressure at that point: then the external forces are the following:—

1. The pressure below A_0 B_0, or $p \times S$.
2. The weight of the loaded piston, or $-$ W.
3. The sum of the reactions due to the frictions of the water against the walls of the cylinder, or $- \phi$.

Each of these forces remains constant during the small motion considered; hence the left-hand side of the equation will be represented by $p\,S - W - \phi$.

We have now to consider the right-hand side, or the loss of momentum. Since the weight W does not move, it has not to be considered. We may also neglect the part $A_1\,B_1\,C_0\,D_0$, which is common to the two masses $A_0\,B_0\,C_0\,D_0$ and $A_1\,B_1\,C_1\,D_1$. The loss of momentum required will therefore be the difference between the momentum of the mass $A_0\,B_0\,A_1\,B_1$, and that of the mass $C_0\,D_0\,C_1\,D_1$. Let D be the discharge per second; σ the section of the escaping water, and w the weight of a unit of volume; the velocity of the water at $A_0\,B_0$ is then $\frac{D}{S}$, and the velocity of the water at $C_0\,D_0$ is $\frac{D}{\sigma}$. The mass $A_0B_0A_1B_1$ and the mass $C_0D_0C_1D_1$ are each $= \frac{D}{g} \times w$. The loss of momentum is therefore given by

$$\frac{Dw}{g} \times \frac{D}{S} - \frac{Dw}{g} \times \frac{D}{\sigma}, \text{ or } \frac{D^2 w}{g}\left(\frac{1}{S} - \frac{1}{\sigma}\right);$$

it is therefore less than $-\frac{D^2 w}{g\sigma}$.

The equation therefore becomes—

$$pS - W - \phi < -\frac{D^2 w}{g\,\sigma};$$

whence
$$p - \frac{W}{S} - \frac{\phi}{S} < -\frac{D^2 w}{g\sigma S},$$

or in the limit,
$$p = \frac{W}{S} + \frac{\phi}{S} - \frac{D^2 w}{g\sigma S}.$$

If we put
$$\frac{D^2 w}{g\sigma S} = a, \quad \text{then}$$

$$p = \frac{W}{S} + \frac{\phi}{S} \quad \ldots\ldots\ldots \quad (2)$$

with a negative error less than a. It will be borne in mind that S is the area of the cylinder, and hence it is the diameter of the bore and not of the piston which must be measured.

2nd. *Error due to the velocity of the liquid filaments.*

We assume the supply pipe leading to the piston to be so large that the water has no appreciable velocity in it. But the water in the cylinder immediately below the piston must have a certain

velocity, which slightly diminishes its pressure. On the othe
the pressure in the metallic manometer is equal to that in the s
pipe, where the velocity is inappreciable.

Let P = the pressure in the supply pipe,
p = the pressure at A_0 B_0, Fig. 7, Plate 71,
v = the velocity at A_0 B_0.

Then $$\frac{P}{w} = \frac{p}{w} + \frac{v^2}{2g}, \text{ or } P = p + \frac{v^2 w}{2g}$$

whence $$P = p + \frac{D^2 w}{2gS^2}, \text{ since } v = \frac{D}{S}.$$

The error β due to this source is therefore certainly less than $\frac{I}{2}$
In practice, with the latest arrangements, the error is still smal

3rd. *Error due to the friction of the water.*

Suppose the piston to be very long: in Fig. 8 let A_0 B_0 l
section of the annular vein near its entrance into the annular
and at the most contracted section; and let C_0 D_0 be a section ne
point of escape. Consider the annular mass A_0 B_0 C_0 D_0, ar
A_1 B_1 C_1 D_1 be its position at the unit of time. The general equ
(1) being again employed, the external forces acting on this ma
as follows:—

1st. The pressure of the water on the section σ at the bott
the annular space.

2ndly, The sum Σf of the frictions of the water against the
of the cylinder.

3rdly, The sum Σf_1 of the frictions of the water agains
piston.

When the clearance is very small, the surfaces of the cylinde
the piston are sensibly equal, and we may consider Σf and Σ
equal. Put $\Sigma f = -\phi$, thus bringing out the negative sign.
resultant force is therefore the pressure on the section σ, less
Again, since the motion is steady, the momentum lost by the
A_0 B_0 C_0 D_0, in passing to the position A_1 B_1 C_1 D_1, is equ
the momentum of A_0 B_0 A_1 B_1 less the momentum of C_0 D_0 C
But if the piston were indefinitely long, the frictions in the an
space would be sufficient to stop any motion of the water, and its

of momentum would consequently be zero. At the same time the pressure at the entrance of the annular space would be equal to p. Let m be the ratio of the contracted section to the full section σ. Then we should have—

$$pm\sigma - 2\phi = 0,$$
$$\phi = m\frac{p\sigma}{2} < \frac{p\sigma}{2}.$$

Since the friction is at the most $= \frac{p\sigma}{2}$ with a piston of infinite length, it will be less than this value with a piston of finite length. Hence if, in equation (2) above, we put $\frac{\phi}{S} = \gamma$, we shall have—

$$\gamma < \frac{p\sigma}{2S}.$$

4th. *Error due to inaccuracy in the weight* W *and in the diameter of the bore.*

If the load W were applied direct, the only possible error in estimating its value would be due to inaccuracies in the weights forming the load, and it would suffice to compare these carefully with standard weights. In the actual arrangement, Fig. 5, Plate 71, the load is given by a movable weight on a graduated lever, and there may be slight errors in this graduation. The lever might be made longer to give greater accuracy, but it would be better to apply the weights direct.

Again slight errors may be made in determining the diameter of the bore. Let a be this diameter, and da be the error in measurement. Then we have—

$$\text{Area} \quad S = \frac{\pi a^2}{4}.$$
$$\text{Hence } dS = \frac{2\pi a}{4} \times da$$
$$\frac{dS}{S} = \frac{2\pi a \times da}{4\pi\frac{a^2}{4}} = 2 \times \frac{da}{a}.$$

The consequent error in the pressure will be $2p\frac{da}{a}$, which we will call δ.

If the measurement of the bore is made at a temperature of about 15° centigrade, the error due to the expansion or contraction of the

metal may be neglected. Assume that observations are alway at a temperature between 0° and 30°, then the greatest vari temperature will be 15°. Now for a variation of 100° the expa steel is equal to $\frac{1}{800}$ of its length. The expansion in this c therefore equal $\frac{15}{100} \times \frac{1}{800}$, or $\frac{15}{80,000}$. This gives a possible proportional error of about 0·0002, or an error in the 0·0004 or $\frac{1}{2,500}$; which may be neglected.

Summary of Errors.

The result of our investigation is the following equation :–

$$p = \frac{W}{S} - \alpha + \beta + \gamma \pm \delta;$$

where $\alpha < \frac{D^2 w}{g \sigma S}$ (error due to momentum neglected)

$\beta < \frac{D^2 w}{2 g S^2}$ (error due to velocity of liquid filame

$\gamma < p \frac{\sigma}{2S}$ (error due to friction of water)

$\delta < 2p \frac{da}{a}$ (error due to measurement of bore).

D is the discharge per second: this may be easily measured particular case, but it will suffice to fix a superior limit to it. friction of the water was nothing, the velocity at the point of would $= \sqrt{2g\frac{p}{w}}$, where p is the pressure, and w the weight p of volume.

But this velocity is also $= \frac{D}{\sigma}$;

hence, in the limit, $\frac{D}{\sigma} = \sqrt{2g\frac{p}{w}}$

$$D^2 = \sigma^2 \times \frac{2gp}{w}.$$

Hence we have—

$$\alpha < \frac{D^2 w}{g \sigma S} < \frac{2p\sigma}{S}$$

$$\beta < \frac{D^2 w}{2gS^2} < p\left(\frac{\sigma}{S}\right)^2.$$

These relations would hold *à fortiori*, if we substituted the piston area s for the cylinder area S.

Application to the apparatus actually in use.

Here the diameter of the bore is 14·2 mm., so that its area $S = 160$ sq. mm. The clearance between piston and bore is less than $\frac{1}{20}$ mm., so that $\sigma = \pi \times 14 \cdot 2 \times \frac{1}{20} = 2 \cdot 23$ sq. mm.

The diameter of the bore is measured correctly to within $\frac{1}{20}$ mm.

If the pressure $p = 200$ kilogrammes per square centimetre, the discharge D is barely 1 cubic centimetre per second: and taking the kilogramme and centimetre as units, we have

$$\frac{\alpha}{200} < \frac{1 \times 0 \cdot 001}{900 \times 0 \cdot 0223 \times 1 \cdot 6 \times 200} < \frac{1}{6,500,000},$$

$$\frac{\beta}{200} < \frac{1 \times 0 \cdot 001}{2 \times 900 \times (1 \cdot 6)^2 \times 200} < \frac{1}{1,000,000,000},$$

$$\frac{\gamma}{200} < \frac{0 \cdot 0223}{2 \times 1 \cdot 6} < \frac{1}{143},$$

$$\frac{\delta}{200} < \frac{2 \times 0 \cdot 05}{14 \cdot 2} < \frac{1}{142}.$$

The proportional errors would be the same for other pressures.

Discussion.

Mr. A. Allan mentioned that in 1859 he had read a paper to the Institution (see Proceedings 1859, page 179) on a new kind of pressure-gauge, in which a correctly measured volume of air was used as a spring, instead of the ordinary metallic spring. The measured air-spring was acted on by cold water from a bent pipe, as usually applied to other pressure-gauges; and the pressure was shown by a water line in a glass tube, as in a barometer. The mode then adopted for testing these air-spring pressure-gauges had been by a well made gun-metal cylinder of 1 sq. in. area, fitted with a ram of the same metal having a carefully turned leather washer on its lower end; the cylinder was vertical, and the cross-head on the top of the ram worked between guides, with side rods carrying a plate below, which was loaded with dead weights of 15 lbs. each, directly under the cylinder. From the bottom of the cylinder a branch pipe went to the air-gauge to be tested; and another to a Bourdon gauge, then considered infallible, which checked each 15 lbs. addition to the load. With the cylinder was then connected a tall glass tube, closed at top and having a space to mark a scale on; and every 15 lbs. weight added on the ram raised the water-line correspondingly in the glass tube, the indications being found to agree nearly with the theory of air compression, according to which the volume would vary inversely as the pressure applied. In reality a continually diminishing scale was obtained up to 200 lbs. per sq. in., which was corrected by many direct experiments, and also by a mercury column. On testing the mercury column itself, there was found to be a constant slight error when it was applied to the pressure-gauges. For instance, after loading the testing ram to 100 lbs., and pumping up the mercury to that pressure, and marking the scale, if it were then further pumped up to 120 lbs. and afterwards lowered again to 100 lbs., the mercury column never came back to exactly the same point in falling as in rising, probably owing to the friction of the metal in the glass tube.

in the present paper it was stated (page 455) that the graduation of sure-gauges could not be fixed by calculation alone; but he hoped the mathematical theory of air-compression this might yet be omplished, and that a correct standard scale and instrument might made for testing all ordinary pressure-gauges up to 200 lbs. per in. by a simple air-column. Variation of temperature would asion no difficulty, as air was equally elastic at all ordinary nperatures; and the necessary operation of blowing the air and ter out of the instrument was favourable to the accuracy of the dications given, because for each gauge tested the testing air-spring ould then be at the temperature of the surrounding air.

About three thousand air-gauges had now been made, and were at ork in various places. In some of them the same air-spring had een in use for six months without change, and in others for twelve onths. Should a doubt arise as to the pressure shown at any time, the air could be blown out, and a new supply admitted, which would settle the question. The advantages of the air-spring pressure-gauge were that it had no metal spring, rack, pinion-sector, or multiplying parts to wear or stick; the air-spring was without cost, and could be renewed at pleasure. On locomotives the water line forming the index had much less vibration than the multiplying pointer of other spring gauges; nor was the air-gauge subject to silting up, on boilers that primed. The instrument, being made of best bronze metal, was not liable to wear by oxidation; the glass tube did not wear like those of water-gauges on boilers, some having been in work eighteen years; and, in the event of accident, any man could replace it. The air-spring pressure-gauge was useful to test others by, and its principle had been approved by various engineers of eminence. The want of a pressure-gauge based on scientific principles would be gathered from the Royal Agricultural Society's trials: out of 265 new metal-spring gauges tested to 50 lbs. during the three years 1868–70, only 37 were found to be correct, the errors of the remaining 228 ranging from 16 to 20 per cent.; and at the Birmingham show in 1876, out of 108 new gauges tested, only 9 were found correct.*

* See Proceedings Inst. M. E., 1871, page 281; and *The Engineer*, 28 July 1876, page 67.

Mr. J. A. G. Ross said the subject of the paper was one great interest, especially with regard to large testing machines there was a liability to very great differences in the pressure in The apparatus described in the paper seemed to meet that i measure. It was not altogether a new thing: ten years ago of that sort had been brought out, having an exactly fitting r cylinder; moreover at the top it had balls similar to governo so that it could indicate without any adjustment from the pressure to the highest, by moving the balls and levers vertical to a horizontal position. The difficulty in that case, he apprehended also in the present case, was that it was im to keep such a gauge in a position where grit would not get small amount of grit in the cylinder caused the gauge to sti so it failed.

He should like to ask Mr. Allan if he had any provis meeting a change of temperature or a sudden rise of pressu course a very sudden rise of pressure produced an incre temperature in the confined air, causing it to indicate falsely; wished to know if a change in temperature, or a sudden rise of p altering the temperature, had been met or compensated for way in the air-spring gauge.

Mr. ALLAN said no sudden change of pressure could take p actual work to develop heat enough in the air-spring ga produce the smallest error; if the temperature was increased cause, the gauge could readily be tested by turning the hand blowing out the water and air, and taking in a new atmospher then it was of no importance whether its temperature wa or 32° F., the spring would be of equal strength.

Mr. Ross thought the absorption of the air by the water difficulty in Mr. Allan's gauge.

Mr. ALLAN replied there was no difficulty from that caus same volume of air would last twelve months in the gauge suffering any absorption; but it might be changed hourly, d weekly.

Mr. W. H. Maw said the apparatus proposed by M. Marié was practically identical with the form of combined pressure-gauge and safety-valve * used by Mr. J. V. Gooch when on the South Western and Eastern Counties (now Great Eastern) railways, between 1850 and 1856: many scores of those gauges had been made and worked. Mr. Gooch had adopted the plan of having side ports, which were uncovered by the piston of the gauge rising above the ordinary working pressure.

The President observed that Mr. Gooch had gauged his indicators by a gauge of that kind.

Mr. R. Lüthy mentioned that some years ago he had designed an apparatus for measuring the pressure in hydraulic presses, and for ascertaining the friction of leather collars; and had carried out a series of experiments for Mr. Hick. All the various pressure-gauges he could get were connected with the apparatus; amongst others he had one with a small piston loaded by a graduated lever and weight, made by Messrs. Joseph Whitworth & Co. He had also a mercurial gauge made by Mr. James Fogg of Bolton, in which the pressure from the pumps or press acted upon a very small piston, which formed part of a very large piston loaded by a column of mercury; the pistons had a very small motion indeed, and were packed with thin india-rubber diaphragms stretched over their surfaces, and secured all round in the fixed portions of the gauge; that he found to be the most reliable and durable gauge, when once properly adjusted. With regard to the friction of M. Marié's piston, he thought it would be much more easily measured in the same way that the friction of leather collars had been measured in the experiments he had made. In those experiments the ram was continued right through the top and bottom of the cylinder; and the weight of the ram being known, as well as the load brought to bear upon it by a steelyard, an exact measure was obtained of the power required to move it under certain pressures. For instance, in measuring the friction of the leather collars, he had a ram passing

* An engraving of this is given in Clark's "Railway Machinery," page 208.

right through a vertical cylinder with a leather collar at each end, and he then weighed how much it took to move the ram up or down, and of course one half of that weight represented the friction of one leather collar.*

Mr. J. Humphrys said that, looking at the ingenious contrivance of M. Marié, there was one objection which had been raised in the paper itself, namely as to the difficulty likely to arise from dirt getting into the cylinder. He should be glad to know whether that difficulty might not be got over by introducing a column of purified oil or some material of that sort, which might remain under the piston and interposed between the piston and the water.

Mr. E. B. Ellington mentioned that a gauge very similar construction was commonly used in chain-cable testing machines was in general use in registering the pressures, but not as a stand the dead weights and levers being depended upon for the more accu measurements. He did not think any gauge of that class, or gauge at all, would supersede the necessity for dead weights levers in accurate measurement.

Mr. R. H. Tweddell thought the members owed their tha to M. Marié for the careful way in which he had gone into experiments, and the able manner in which he had considered subject mathematically. Although he had thereby simply pro what had been already found out in practice in this country, it satisfactory to find the practice was confirmed by theory. So as the application of any gauge to ordinary hydraulic machine was concerned, he failed to see any necessity for it, because accumulator was both the best safety-valve and also the best measu of pressure that could be used; in fact it was only another form an enlarged scale of the apparatus shown in the diagrams; where it was a question of testing machinery, where the utm

* A description of this apparatus with the results of the experiments published in *The Engineer*, 1 June 1866, page 393.

accuracy was a matter of extreme importance, the investigations in the paper possessed great interest. He had never found gauges on hydraulic machinery reliable for any length of time, owing to the shocks and vibration of the machinery they were attached to. A very simple expedient was sometimes used. The face of the gauge had two lines of figures, one on either side of the vertical centre line; and each had its own pointer, which moved in opposite directions, one checking the other. He might mention that all the indicator diagrams which had been given at the Paris meeting by M. Berrier-Fontaine (Proceedings 1878, p. 346) had been obtained by an ordinary steam indicator, which he had altered by simply reducing the area of the piston. He believed he was the first to take indicator diagrams at any such pressures—from 1,500 lbs. to 2,000 lbs. per sq. in.

M. Marié said in reply that Mr. Allan had spoken only of low pressures, while the apparatus described in the paper was for high pressures. For low pressures it was easy to have a good standard gauge.

With regard to the question of dirt coming between the piston and the bore, that was a difficulty no longer. A filter was employed to test if there was any dirt in the water; and it was now found that the water was not dirty once in a hundred times. It was not necessary therefore to employ oil, as ingeniously suggested by Mr. Humphrys.

He had not heard of any English apparatus of that kind, and he should be glad to have the drawings of any such that had existed. He was well aware that the principle of the apparatus was very old; the ordinary Watt's indicator was in fact an apparatus of that kind, since it had a piston without any packing, the principle being thus exactly the same as in the present apparatus. The apparatus which Mr. Gooch had employed appeared also to be the same as Watt's indicator. Yet this system had never previously been employed for the graduation of gauges, because it had never been known how to measure the friction of the piston. He believed the method he had given for measuring that friction was new, as well as the general arrangement of the apparatus described in the paper.

Gauges having a piston packed with diaphragms had been con employed for fifteen years in the works of the Paris and Railway, and had always given trouble by friction; and because the friction of the diaphragms had been found to great, that he had been led to look for a new method of mea high pressures. The apparatus described for this purpo designed for very delicate measurements; it was not intende for ordinary use in daily practice, but for graduating by it gauges to be employed in ordinary practice.

In conclusion he might mention that he had lately compar standard gauge with a metallic gauge, which had been gradua M. Amagat by comparison with an open-tube gauge in a shaft, as described in the paper; and they had been found to exactly.

The PRESIDENT proposed a vote of thanks to M. Marié paper, which was carried by acclamation.

The PRESIDENT proposed the following votes of thanks, were carried by acclamation:—

To the Mayor of Barrow, Edward Wadham, Esq., for hi reception of the Members at the present Meeting, hospitality in entertaining them at luncheon.

To Sir James Ramsden and the Proprietors of the various in Barrow and the neighbourhood, open to the visit Members, for their kindness in inviting the Members their Works, and for their arrangements and hospita connection with the visit.

To the Furness Railway Company, for their kindness in present Members with Free Passes over their lines, and for the facilities arranged for the Excursions.

To the Barrow Yacht Club, for the arrangements so kindly made by them for facilitating the accommodation and convenience of the Members visiting Barrow.

To the Honorary Local Secretaries, Mr. Charles Smith, and Mr. C. J. Copeland, for their very valuable services in suggesting and maturing all the arrangements for the success of the Meeting.

The Meeting then terminated.

EXCURSIONS.

The following Works in and around the town of Barrow wer thrown open to the Members in the course of the week:—

The Barrow Hæmatite Steel Works.
The Barrow Shipbuilding Works.
The Barrow Flax and Jute Works.
S. J. Claye, Railway Rolling Stock and Steel Works.
Furness Railway Works.
William Gradwell, Saw Mills.
Woodhouse and Sons, Brick Works.
Cooke and Swinnerton, Wire Works.
Westray Copeland and Co., Engineering Works.

On the afternoon of Tuesday, 3rd August, the Members were entertained at luncheon in the Market Hall by the Mayor, Edwar Wadham, Esq. After luncheon an excursion was made by specia steamer from the Buccleuch Dock to the Ramsden Dock, describe in Mr. Stileman's paper (*ante*, p. 324). The Members inspected no only the docks themselves, but also the grain warehouses an elevators, and the sheds and other arrangements for receiving slaughtering, and storing cattle and pigs imported from America. Th appliances included a refrigerating machine for the dead meat store in which the cold is obtained by the expansion of compressed a

From thence the Members walked to the Barrow Shipbuildi Works, where an opportunity was afforded of seeing the steams *City of Rome* in course of construction, as described by Mr. Ja Humphrys in his paper (*ante*, p. 336). A portion of the engine plate for this vessel, weighing 34 tons, was successfully cast du the visit; the pouring being done from 4 ladles, and lasting $1\frac{1}{2}$ minute. The other vessels under construction at the ti

visit were five gun-boats for the Admiralty, each of 460 tons, ı engines of 360 H.P.; the *Furnessia* of 5500 tons, with 4000 '. engines, length 445 ft., beam $44\frac{1}{2}$ ft., building for the Anchor e; the yacht *Aries* of 300 tons, for Sir James Ramsden; two er ships for the Société Générale de Transports Maritimes de rseille, of 3800 tons and 2500 H.P.; a 4000-ton ship, specially ıstructed for carrying live cattle; two ships of 1500 tons for the Andrews Steamship Co.; one of 2000 tons for Messrs. Lamport l Holt; and two steel vessels of 4100 tons and 4000 H.P. for the ninsular and Oriental Co. A new arrangement of Tweddell's draulic riveter was seen in operation on the frames of some of ese vessels, and another on the keel of the *Furnessia*, setting up rets of $1\frac{3}{16}$ in. diameter and 8 in. length. Appliances for the ectric light were in course of erection, to assist the carrying on of ıe work during the night, which was rendered necessary by the reat amount of orders in hand, forming an aggregate of nearly 0,000 tons.

The works themselves, which are among the most extensive in the orld, are shown in plan on Plate 34. They are divided by the sland Road into the engineering department and the shipyard. On he north side of the former is a building containing the coppersmiths' hop, the engineers' smithy, and the brass foundry: the latter ontaining, besides seven ordinary pot furnaces, a large reverberatory urnace for brass castings of the heaviest class. On the south side of he engineering works are two large buildings, one containing the ron foundry and boiler shop, and the other the fitting and the recting shop respectively. In the boiler shop the boilers for the *'urnessia* and for the *City of Rome* were seen; the shells and tube-lates had been drilled by a multiple drilling machine designed by Ir. James Humphrys, and capable of putting in eight holes at once. The engine shop is 450 ft. by 150 ft., and contains a large number f heavy tools, especially a double-standard slotting machine, driven ith a belt velocity of 1900 ft. per minute.

The shops in the shipyard are arranged in a hollow square, ljoining the Island Road. On the east side are the offices and aller shops; on the north the frame-building shed, smiths' shop,

&c.; on the south the joiners' shop, saw mill, boat-building shop, cabinet shop, &c.; and on the west the machine shed, containing punching and shearing machines, &c. Immediately beyond this lie the slips, consisting of a covered slip for yachts, and twelve other slips, of which the largest are capable of taking vessels up to 1,000 ft. in length.

From the shipyard the Members were conveyed by special train to Lakeside (Windermere) on an evening excursion, in the course of which they were entertained at dinner by the Barrow Shipbuilding Company, the Barrow Flax and Jute Company, Mr. S. J. Claye, Mr. W. Gradwell, and Messrs. Westray Copeland & Co.

On Wednesday afternoon, 4th August, the Members first proceeded to inspect the goods locomotive built by Mr. Webb, and fitted with Mr. Joy's valve gear (see *ante*, p. 432).

They then walked to the Barrow Flax and Jute Works, where the various processes described in Mr. Fleming's paper (*ante*, p. 380) were exhibited and explained. In the preparing room on the ground floor, into which the softened stricks of jute are conveyed from the "batching" room adjoining, there is one row of breaker cards, then a row of finisher cards, a row of first drawing frames, a row of second drawing frames, two rows of roving frames, and two rows of spinning frames. All these machines are usually in motion, and the material leaving each row of machines passes on at once to the next row. The bobbins of spun yarn are then conveyed into another room, where the beams are prepared for the looms; and thence the beams are transferred to the weaving room, where upwards of 400 looms of various sizes are at work, for the production of sacking, bagging, tarpauling, hessians, striped bedding, jacquard window-curtains, table-cloths, counterpanes, &c. The looms are employed on different qualities of jute, from the fine

material made from line yarns for "Kalameit" to the roughest nail-bag sacking; and from tapestries and cloths of attractive designs and colours to common plain bedding material. The shafting is all underground, so that all belting from the roof is obviated, and at the same time the main bearings are less exposed to choking with the dense fluff, which settles so thickly that the whole of the machines have to be thoroughly cleaned at the end of each day's work. After having been inspected, the cloth passes through the calendering and finishing processes, which are performed by special machinery. The cloth is then wound up through slits in the ceiling into the storey above, where it is lapped by machinery in readiness for packing, and where also the sacking is cut into proper lengths and then sewn by machines working with three different kinds of stitch. Small wagons on rails convey the bundles of cloth into another room, where goods for shipment are pressed by hydraulic presses into bales of great solidity, which are covered with jute-cloth and hooped with steel bands. In the same room several printing machines are employed in printing names on the finished sacks. The average output of the works is 140 tons per week; and 1700 hands are employed in the factory, in addition to fully 300 occupied at home in sack-sewing.

From thence the Members proceeded to the Barrow Hæmatite Iron and Steel Works. These are shown in plan on Plate 34. It will be seen that the Iron Works on the west and the Steel Works on the east are separated by a wide tract of land, occupied by sidings &c., and by a group of Coppée coke ovens. The Iron Works consist mainly of a row of twelve blast-furnaces, all of about the same dimensions, 62 ft. high, with boshes from 18 to 21½ ft. diam. One furnace has three Whitwell stoves, 50 ft. high and 18 ft. diam.; two others have Cowper stoves of the old type; the rest have the ordinary cast-iron pipe stoves. The Cowper stoves are about to have the more recent improvements added, which will double their power and enable them to blow four furnaces. The pig beds are all on the east side of the furnaces, and face toward the sidings above

mentioned. On the west side are the hot-blast stoves, twent blowing engines with their boilers, and also workshops, locom shed, &c. The ore-mixing sheds lie to the east, beyond the si adjoining the pig beds, and from these the furnaces are serv inclined hoists, working wrought-iron carriages so built as t their upper platforms horizontal. Each hoist is worked by of winding engines, the winding drums being driven by frictio and fitted with steam brakes which bear into the grooves of the The charge per ton of iron made is about 35 cwt. of ore, 10 limestone, and 21 cwt. of coke. About one-third of the make for steel making; and this is all carried to the converter molten state, and used direct. For this purpose the metal down the pig bed in an ordinary sand channel, and falls into ladle mounted on a wagon, which is brought into positio sunken siding immediately under the boundary wall of the p Each ladle holds about 8 tons of metal. When full, the i stopped off, the surface is covered with coal dust, and the l conveyed over about 1 mile of railway to the converter, w suffering any serious loss of heat.

The Steel Works consist of three large parallel sheds, converters &c. at the northern end, and the rolling mill finishing machinery at the southern end. There were converters at work, producing altogether from 2500 to 300 per week, the production per converter being much greate formerly. A 6-ton Siemens furnace is also at work, and two furnaces are in course of construction. Raised sidings hav made at each end of the Bessemer department for the entrance wagons containing the molten metal, which is thence disc direct into the mouth of the converters. Immediately to the of the converters are the steam hammers with their furnace beyond these are two cogging mills, one with 30-in. and one with rolls, driven by a pair of beam engines, and fitted with rev gear. These mills deal with ingots up to 35 cwt. each, and dispensed with several hammers formerly in use. South of are two three-high rail mills with 26-in. rolls, a Gallowa

mill, and a 26-in. two-high reversing rail mill. This mill is driven by a pair of horizontal engines, with Corliss valves worked by eccentrics; and the reversal of the motion is effected by shifting the eccentrics on the shaft. At the extreme end of the sheds are the rail saws, and the rail-straightening, punching, and drilling machines. To the south of the sheds is a range of seventy-two gas producers, supplying gas to the reheating furnaces, which are all on the Siemens egenerative system. To the east are the blast engines for the Bessemer plant, with range of boilers; and beyond these, adjoining he Walney Road, are the offices, workshops, and laboratories, the atter containing a testing machine of 100 tons maximum pull.

In addition to the inspection of the works, the Members witnessed he casting of steel ingots under steam pressure, on the plan described y Mr. Davis (*ante*, p. 396). On this occasion the top was keyed on o the ingot mould, and the steam pressure applied, in less than 30 seconds after the pouring was finished. They also witnessed the proof of a small boiler of mild steel, which Mr. J. T. Smith had kindly had prepared some time before at the President's request, in order to show the effect of excessive pressure, applied to tough ductile steel, in making the rivet-holes draw and the seams leak, without producing any ripping, cracking, or bursting effect. The boiler, shown in Figs. 20 and 21, Plate 56, was made of $\frac{1}{4}$-in. steel plates, with dished or concave ends, the diameter being 48 in., diameter of rivets $\frac{1}{2}$ in., and the pitch (double-riveted) being $1\frac{7}{8}$ in. on one longitudinal joint, and 2 in. on the other. At 360 lbs. per sq. in. the leakage in the $1\frac{7}{8}$-in. joint became so great as to overpower the pump. It transpired that the boiler had been similarly tested on the previous day, when a pressure of 420 lbs. was attained, and the leakage then overpowered the pump.

In the evening the Annual Summer Dinner of the Institution was held in the Market Hall, the President in the chair, and was largely attended by both Members and guests.

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where they were entertained at luncheon by t
by Mr. Wadham, Mr. Aymer Ainslie, and M
The plant consists of four furnaces, height 75
diam. at hearth 8 ft. The blast is supplied
direct-acting blowing engines, 32 in. steam
cylinders, fitted with expansion gear and inje
are eight pipe-stoves to each furnace, fired
giving a total heating surface of 9600 sq.
each consisting of a brickwork tower, divided
One of these serves as a staircase, and the o
which are lifted and lowered alternately by
engines at the top. The boilers, seventeen
by the waste gases, which are mixed with
combustion chamber placed in front of each
through the boiler flue, which is single, e
tubes, return underneath the boiler, and the
the smoke flue. The gantry has ten spans, a
gradient of 1 in 144, sloping from one end
raised by a direct-acting steam lift, diam. o
of piston-rod 5 in., to the other end where
direct-acting hydraulic drop on the ca
production is about 550 tons per furnace

Excursion No. 2 proceeded first to the Mines at Park and Roanhead, the former belonging to the Barrow Hæmatite Steel Company, and the latter to Messrs. Kennedy Brothers. At Roanhead they were entertained at luncheon, by kind invitation of Mr. Myles Kennedy. Some Members descended the "Plunger" pit, while others inspected a safety apparatus for cages, in which the breaking of the rope released india-rubber tension springs, and thereby forced eccentric toothed sectors against the vertical guides, the cam action of these sectors increasing the grip. Kennedy and Eastwood's improved rock drill was also seen, boring 1¼-in. holes in mountain limestone at about 5 in. per minute. The air cylinder, 12 in. diam., admits the air through holes pierced round the middle of its length, so that the compression takes place during the latter half of the stroke only; admission valves &c. are thus done away with. At the "Wilfred" pit was seen a winding engine with brake sheave on the drum shaft, and brake blocks applied direct by a short single-acting steam cylinder.

From Roanhead the party walked to the new sinking of the Sandscale Mining Company. Owing to the great amount of water found in the sand, the Gill system of sinking was about to be adopted; but as the apparatus had not arrived, the company were using one of Mather and Platt's shell pumps, which is worked as follows. A rope from a steam winch passes down the shaft, and is attached to the piston-rod of an iron cylinder about 10 ft. long by 2 ft. diam., with a sharp bottom edge. The piston has an india-rubber valve opening upwards; and sand is gradually forced through this valve into the space above the piston by alternately dropping the cylinder to the bottom and lifting it again. When the cylinder has thus been filled, the sand is emptied into a reservoir in the bottom of the shaft, from which it is raised by a second rope; only a portion of the bottom being acted upon at one time by the dropping cylinder.

In the Gill system of sinking, a vertical steam cylinder is fixed at the top of the shaft, having a hollow piston-rod passing through both cylinder-ends. Through this rod a rope passes, and is clamped to it when required. The rope is led down the shaft, and attached at the bottom to the pump-rod of a bucket pump, fixed on the top of a wrought-iron vertical receiver. This receiver has a removable

bottom, to which is fixed an inlet pipe, which passes up through bottom and reaches to within 6 in. of the top. The rope is slacked out enough to let the pump bucket fall to the bottom of pump barrel: it is then clamped to the piston-rod of the steam cylin and steam is admitted to raise the piston. This in rising draws up rope and pump bucket, and thus sucks the sand up through the i pipe, a certain amount falling over the top of the inlet pipe into interior of the receiver. The same happens at each stroke of steam cylinder, until the receiver is full. The rope is the unclamped, the receiver is drawn up to the top of the shaft, emptie by removing the bottom, and lowered again; and the process then begins afresh.

From Sandscale the party walked to the Blast Furnaces at Askam. Here there are four furnaces, each capable of making 500 to 550 tons per week. The gantry lift is of the direct-acting steam type, but the furnaces are served by inclined lifts, similar to those at the Barrow Steel Works. The blast is produced by six vertical blowing engines, four of them having the crank-shaft at the floor level, the steam cylinder above, and the blowing cylinder above this again, with the slide-bars and cross-head between the two. One of the engines has a piston-rod 15 in. diam., giving a diminished piston area in the downward stroke, to counterbalance the descending weights. The engines are compounded together in threes, the central engine being fitted with condenser and air-pump, and receiving the exhaust steam from both the other engines.

Excursion No. 3 was to the Millom Blast Furnaces and Hodbarrow Mines, situated in Cumberland to the north of the Duddon estuary (see Plate 46). The party proceeded by special train to Millom, where they were entertained at luncheon by the Cumberland Iron Mining and Smelting Company, represented by the managing director, Mr. Thomas Massicks, and the Hodbarrow Mining Company, represented by the manager, Mr. Cedric Vaughan. They then inspected the Millom Blast Furnaces, which were started about fifteen years ago, but have recently been entirely rebuilt, with all the most modern improvements. They are 70 ft. high, 21 ft. diam.

nes, and produce each about 500 tons per week. There are lowing engines, three being of the inverted direct-acting class, two being beam engines, with the piston-rod attached between connecting-rod end of the beam and the centre, so that the n-stroke is 9 ft., while the crank-stroke is 11 ft. The blowing ders are at the other end of the beam, and are 100 in. diam. condensing water is supplied by one of Hathorn Davey & Co.'s und direct-acting pumping engines. The works are remarkable extensive and complete system of Whitwell stoves, the capacity ch was being further increased at the time of the visit; and ir extensive depôt accommodation for the storage of iron ore, c. The railway wagons travel from the branch connection e Furness Railway by gravitation to a vertical hoist, by which e lifted 35 ft. high to the top of the depôt. The railway at of the depôt has a slight inclination downwards, which admits wagons being placed without power wherever they are required lischarged; and when empty they run down a long incline the Furness Railway. Over 7,000 tons per week of raw l are thus discharged, so that this self-acting arrangement has rable importance. The company are extensive mine-owners the Cumberland and the Furness hæmatite districts.

nce the party were taken by an engine to the Hodbarrow which are among the richest and most extensive in the te district. They first saw a great circular hollow, about 500 ft. y 60 ft. deep, marking where the surface had sunk down over ed-out basin of ore. There are several such basins in this mine, gest of which is still unworked. At the "Arnold" pit a new cting pumping engine was exhibited, 70 in. cylinder, 9 ft. A new sinking was also seen in progress, carried on under by Mather and Platt's process, a diver being employed to boulders occurring in the clay, which were obstructing the t of the cylinders.

parties from all three excursions were united at Foxfield on, and taken by special train to Coniston, where they dined r in the grounds of the Waterhead Hotel. An excursion was

afterwards made on the lake in the steam gondola, a small steamer which has worked on the lake for 21 years, and still retains her original boiler, of the semi-portable type, with crucible steel fire-box.

On Friday an Excursion was made to Windermere, by the kind invitation of the Barrow Hæmatite Steel Company. The Members were conveyed by special train to Lakeside, where they embarked in the steamer *Swan*, and traversed the whole length of the lake to Ambleside. After a short stay there the steamer returned to Bowness, where the party were hospitably entertained at luncheon by the Company, Mr. Schneider occupying the chair. On this occasion he gave some interesting particulars as to the rise of the Furness iron industry, for which see *ante*, p. 377. After luncheon the party were again conveyed to the head of the lake, and thence returned to Lakeside, whence a special train brought them to Barrow.

Institution of Mechanical Engineers.

PROCEEDINGS.

OCTOBER 1880.

The AUTUMN MEETING of the Institution was held in the Memorial Hall, Albert Square, Manchester, on Friday, 29th October, 1880, at Three o'clock P.M.; EDWARD A. COWPER, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed.

The PRESIDENT announced that the Ballot Lists for the election of Members had been opened by a Committee of the Council, and that the following New Members were found to be duly elected:—

MEMBERS.

WILLIAM WORBY BEAUMONT,	London.
RICHARD WILLIAM DEACON,	Sourabaya, Java.
JAMES DONALD,	Bombay.
ROBERT PILE DOXFORD,	Sunderland.
OSWALD WILLIAM ELLIS,	Edinburgh.
JOHN HARRY HALLETT,	Cardiff.
JOHN ROBERT JEFFERIES,	Ipswich.
THOMAS MASSICKS,	Millom.
THOMAS SUTTON,	Barrow-in-Furness.
THOMAS WILLIAM THOMPSON,	Birkenhead.
JOHN WILLIAM HUDSON WESTMORELAND,	Nottingham.
WILLIAM YATES,	Manchester.

The PRESIDENT announced that the President, two Vice-Presidents, and five Members of Council, would go out of office at the ensuing Annual General Meeting, according to the Rules of the Institution; and that the list of those retiring was as follows:—

PRESIDENT.

Edward A. Cowper, . . . London.

TWO VICE-PRESIDENTS.

Charles Cochrane, . . . Stourbridge.
Francis W. Webb, . . . Crewe.

FIVE MEMBERS OF COUNCIL.

Henry Chapman, ... London.
David Greig, ... Leeds.
Thomas R. Hetherington, . . Manchester.
Arthur Paget, . . . Loughborough
George B. Rennie, . . . London.

The whole of the above gentlemen offered themselv re-election, and he therefore presented the above list as the retiring Members of Council who offered themselves election at the next Annual General Meeting.

In addition to these he nominated the following Meml candidates for election at the same Meeting :—

Election as Member.	VICE-PRESIDENT.	
1859.	Daniel Adamson, . . .	Manchester.
	MEMBERS OF COUNCIL.	
1856.	Charles Markham, . .	Chesterfield.
1861.	Samuel W. Johnson, . .	Derby.
1865.	Francis C. Marshall, . .	Newcastle-on-'
1865.	Bernhard Samuelson, M.P., .	London.
1866.	Sir James Ramsden, . .	Barrow-in-Fur

According to the Rules of the Institution, it was now open gentleman to propose any name in addition to those candidates

Mr. R. Price Williams begged to nominate as a Meml Council :—

1847. Richard Peacock, . . . Manchester.

The President reminded the Meeting that if any Member had any motion to propose at the Annual Meeting, notice must be given of it at the present Meeting.

No such notice was given, and the following paper was then read:—

ON RECENT IMPROVEMENTS IN THE MACHINERY FOR PREPARING AND SPINNING COTTON.

By Mr. ELI SPENCER, of Oldham.

The present paper has been written in compliance with the request of the President, and is intended to describe the main improvements in Machinery for Preparing and Spinning Cotton, made since the date of the paper read before the Institution by the late Mr. John Platt, at the meeting held in Manchester in 1866.*

Opening and Cleaning Machines.

Machines for opening, cleaning, scutching, and forming cotton into laps, to be fed up to the carding engines, have undergone very little change in design since 1866; but changes have been made to economise labour by shortening operations, *e.g.* the use of single instead of double machines, and a better disposition and arrangement of the machines in the mills.

The Carding Engine.

The principal change under this head has been the supplanting of the finisher carding engine by the combing machine.

For carding cotton for coarse numbers or counts, the roller and clearer engine is still preferred; but for medium and fine counts the self-stripping flat card is much more extensively used. This machine is now made with a great perfection of accuracy, and supersedes to a large extent that class of labour in the cotton mill which is the most difficult to control.

Steel instead of iron wire is now more generally used for card teeth. Its advantage over iron is that it can be drawn finer, and will thus give more points in a given surface; it also admits of being hardened, and carries a finer point; while, as the hard points keep their sharpness for a longer period, less grinding is required, and the wear and tear are reduced.

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* See Proceedings, 1866, p. 199.

The Combing Machine.

Cotton intended to be worked into the finer qualities of yarn is now generally combed, instead of being carded by a finisher card. The combing machine is thus becoming one of the most important machines in the cotton trade. On its introduction to this country in 1851, it was used for Nos. 200 to 300 only (where No. 200 means that 200 hanks, each containing 840 yards, weigh 1 lb.); but in recent years, owing to the demand for a better class of yarns, for sewing and other purposes, its use has rapidly extended, and at the present time numbers as coarse as 30 to 40 are made from combed cotton. When a clear, strong, and uniform thread is required, the combing machine is indispensable, as it completely separates the long fibres from the short ones, which the carding engine does only partially.

Cotton that is to be combed is opened, cleaned, and carded on the breaker card, and the sliver is delivered into cans. A number of these are put up behind a drawing frame, and their slivers passed through it, to be drawn, straightened, and laid parallel. By drawing the slivers once or twice through the drawing frame, the loops and kinks are to a great extent taken out, and less waste is made. About fourteen cans of the sliver, thus made on the drawing frame, are doubled, and united at the lap machine so as to form a lap 7½ inches wide, which is then passed through the combing machine.

The details of this machine are so well known from papers and books already published,* that a full description is unnecessary here.

The machine invented by Heilmann was the first successful machine for combing cotton, and in its principal features it remains as it was originally brought out. Many attempts have been made to supersede it, by Lister, Whipple, Imbs, Lacour, Heilmann-Ducommin, and others; but it has always maintained its position. Its mechanical details however have been much improved during the last ten years, in order to obtain higher speeds and greater production; and now 80 nips per minute are obtained, whereas formerly not more than

* See "Great Industries of Great Britain," by Cassell Petter & Galpin, page 291.

application of nipper cams at both ends (
prevented, and a better nip is secured; (
made of 8 to 10 heads, or deliveries in 1
(4) All the cams for giving reciprocating
afresh; they are now cut by machiner
increased speed, and greater production are e
stop motion has been applied, to stop the
breakage, or when the lap is run off; (6)
been applied to the coiler, to stop the mach
or when breakage of the sliver at the draw
apparatus, to stop the machine when th
introduced; (7) A motion has also been ap
movement to the comb brush, for the bette
comb.

The Drawing Fram

The general arrangements of this mac
72, are the same as described in the f
improvements in detail have been introduce
Fig. 1, are case-hardened, so as to resist th
them. The gearing for connecting the four
rollers is arranged at the driving end of t
that each roller starts at the same time; t
and uniform drawing of the cotton sliver t
is made at both ends, as heretofore. It also

h larger diameters than those formerly used, and are capable of ring much finer variations in the "count" or weight of the sliver roduced. When the draft is changed, no difference is made in the intermediate or "breakage" drafts. The operation of changing is so much simpler that less skilled "carders" or overlookers may be employed: in the old arrangement the relation between the several rollers was so difficult to understand that mistakes were continually being made. It was then found more convenient to change the draft between the third and fourth rollers than between the first and second, *where however the change ought to be made*, since the greatest amount of elongation of the sliver takes place here.

A much more substantial and convenient support is given to the gearing, as shown in Figs. 2 to 5, Plate 72; the drawing operations are thus made smoother and easier, and the quality of the slivers is improved. Front stop motions are now universally employed, and are made very sensitive and quick in action; a great deal of waste is thus prevented and better work is produced. The back stop motions are also constructed to act with greater promptitude when a sliver breaks, thereby stopping the frame before the broken sliver has passed under the back roller, and enabling the piecing to be made before the end is lost, as seen at B in Fig. 1.

The Knocking-Off motion, Fig. 1, is the apparatus by means of which these various stop motions are enabled to stop the machine. It is similar to the old one in its principal features; but it is simpler and easier in its action, and requires very little force to bring it into operation; consequently it acts very quickly, and is not liable to derangement. At C, Fig. 1, is an eccentric, which causes the inclined rod D to reciprocate, and at the upper end of this rod is a slot E oblique to the length of the rod: midway upon the rod stands a projecting snug, ready for lifting the bar F out of a notch at the proper time, and liberating it. A lever fastened on the oscillating shaft G carries a stud, which fits into the oblique slot E in the rod D; and the weighted lever H, also fixed on the shaft G, keeps the stud pressed against the outer end of the slot, so that the shaft G is rocked by the reciprocating movement of the rod D.

The knocking-off action may be illustrated by the Back Stop

motion, Fig. 1. The cotton sliver passing over the tumbler E broken, and the tumbler has been liberated, which allows it lever end to drop, and so to come in contact with an arm from the back of the shaft G, and thereby to arrest th of the shaft. The stud E thus becomes stationary; and continuing its reciprocating motion, the oblique slot causes end of the rod to rise upon the stud, and so brings the stop up against the bar F, which, being thus lifted and from its notch, shifts the driving strap from the fast to pulley.

The Front Stop motion is also shown in Fig. 1. funnel-shaped guide, through which the drawn sliver pas way from the front roller to the pair of calender rollers K. passes in at the large end of the funnel, and out at the s which is contracted until it requires a considerable pull to cotton through it. The guide J is carried on the front end of which the back end I is the heavier, and tends to tilt upwards. L is a reciprocating rod, connected with a the oscillating shaft G, and having a notch in its front e heavy tail I of the guide lever, when liberated by the br the sliver, drops into this notch, thus arresting the moti rod L, and therefore of the shaft G and stud E. This b stop motion D F into action as before described, and at once machine.

A Can Stop motion is now used, which stops the mach the receiving can is full. This apparatus consists of a false to the coiler wheel M, Fig. 1. The plate N forming this fal is weighted by a ring above, which is varied in weight to count of sliver to be contained in the can. The finer th the lighter the ring. Fine drawings will not admit of bein so tightly in cans as coarse ones. When the can is filled su to lift up the loose plate N close to the coiler wheel M, stop S is raised in front of the end of a reciprocating bar P, c with the oscillating shaft G, and the machine is stopped described.

It is found very advantageous to put the same length

sliver in each can, so that when they are all placed up to the next passage of drawing, or to the slubber, they will all be emptied at the same time. By this means the attendant knows which cans require replacing, without looking into more than one. When the quantities in the cans vary, the "tenter" is compelled to look well after them, otherwise the machines will stop very often. Another great objection to the old system is the liability of the can to be filled until no more can be forced into it, thus damaging the sliver and often breaking the coiler tops. By using the can stop motion the work of the tenter is more systematic, and a greater weight is got through the drawing frame with at the same time a slower speed of the front roller.

The use of loose-bossed top rollers has now become almost universal for drawing frames, Fig. 1. Another important improvement in drawing frames is the application of a patent Clearer for the top rollers. It consists of an endless clearer cloth, driven positively by gearing at a very slow rate, with arrangements for stripping it mechanically. Its great cost however has prevented its general adoption.

Electricity has in some instances been employed as a stop motion in these machines, with more or less success; but its adoption has been by no means general, and the limits of this paper will not permit further observations upon it.

Slubbing, Intermediate, and Roving Frames.

The improvements introduced into slubbing, intermediate, and roving frames consist of better winding apparatus, stronger spindles, steel flyers, case-hardened rollers, stopping and lock motions &c.

On the question whether the bobbin or the flyer should lead, in the winding of the thread or sliver upon the bobbins in these machines, there has been a great change in practice since 1866 (see Proceedings 1866, p. 222). Formerly nearly all machines were made with the flyer to lead, especially when pressed flyers were used; whereas now the demand of the trade is almost universal for the bobbin to lead. The latter arrangement increases the duty of the differential motion, and requires more perfect control of this apparatus. Hence the cones employed for driving the differential

[illegible] the spindle [illegible]
[illegible]
[illegible] differential apparatus [illegible]
account of the belt cannot take up the bac
the flyer leads there is a tendency to stretc
bobbin leads there is a slight slackeni
however is immediately taken up when t
motion.

Attempts have been made from time to ti
and belts for regulating the winding of thes
metallic apparatus; but hitherto they have

The increased speed of spindles, and t
pressed flyers, *i.e.* with a presser on one l
necessary to strengthen the spindles, to e
extra duty imposed upon them. A higher
now required to produce the quality of w
competition. This has done much to h
collars or bearings, to enable the spindle
the comparatively unbalanced single-press
practice that nicer work can be obtained f
than from double-pressed: this is espec
finer hank rovings, say above 9 or 10 h
effect produced by the double presser up
undesirable one; and the finer the count
objection.

roving. The pressed bobbin contains about double the quantity of roving, and lessens the labour of "creeling" in the after processes.

The best flyers are now made of solid steel. They are much lighter, will stand a much finer polish, and allow of being worked into shape without fear of cracks inside their hollow legs. The slightest roughness inside the legs catches the fibres of cotton, and causes the work to be badly done, and the ends of the sliver to break.

Machines have long been made to stop when a sufficient quantity of roving has been wound on the bobbins. The best kind are now fitted with a lock motion, Fig. 6, Plate 73, by which, after stopping, it is rendered impossible to set the frame to work again until the full bobbins have been replaced with empty ones, and all is made ready for another start. Before this improvement was applied, tenters had a bad habit of setting the frame to work again, after the ordinary stop motion had stopped the frame, by holding the strap on the fast pulley, until the bobbin was as large as the flyer would permit without breaking the ends. The result was very bad work; the slivers were stretched and made very rough, and the flyer legs were often strained out of their proper position and balance.

This Lock motion, Fig. 6, Plate 73, is controlled by the rack of the cone motion. C C are the cones for driving the differential "jack-in-the-box;" the strap A is slid along them by the forks F F, which are fastened to one end of the rack D sliding in a grooved rail E. At the other end of the rack is an adjustable bracket B. Gearing into the rack D is a pinion on the vertical shaft G, at the top of which shaft is a cord pulley. The weight H suspended from the cord tends to turn the shaft G and its pinion, and so to make the rack travel towards the cones. At the bottom of the shaft G is a ratchet wheel J, controlled by the well known apparatus called the "box of tricks." This apparatus allows the ratchet to turn on its axis through one tooth, at each rise and each fall of the lifting rail which carries the bobbins. Each rise and each fall of the lifting rail corresponds with one layer of roving wound on the bobbin. The strap A is thus gradually traversed from one end of the cones to the other, by means of the motion of the shaft G, communicated to the rack D.

The ordinary setting-on rod MM slides endwise in the frame,

and is connected with the strap-guider of the fast and loose driving pulleys; NN are the ordinary handles used by the tenter for starting and stopping the frame; and K is an arm fixed upon the setting-on rod M. The slide-bar I L, sliding in fixed brackets, has two notches in it, I and L, and carries a projecting lug P, to which is hooked one end of a coiled spring (shown broken), its other end being hooked to the fixed bracket T on the frame; the spring therefore tends to pull the slide-bar I L towards T, into the position indicated by the dotted lines. Catches ready to fall into the notches I and L are carried upon arms turning loose on a centre-pin, from which is also suspended the lever R. On this lever is a stud S, which is suitably placed for acting on the tail ends of the catches, and is shown holding the left-hand catch clear above the slide-bar I.

The parts are shown in the position they occupy just previous to the lock motion being brought into operation. The right-hand catch is resting in the notch L of the slide-bar, thus preventing the spring from moving it. When the bobbins are full, the bracket B will have pushed the lever R far enough aside, as shown by the dotted lines, to lift the catch out of the notch L; thus releasing the slide-bar, and allowing the spring to pull it towards the right-hand, and with it the setting-on rod M by means of the arm K, and so to shift the driving belt from the fast to the loose pulley, and stop the frame. The tilting of the lever R, as shown in dotted lines, removes the stud S from contact with the tail end of the left-hand catch, and allows this catch to fall into the notch I of the slide-bar, thereby locking the slide-bar in the position indicated by the dotted lines.

The left-hand catch and the upper part of the lever R are enclosed within a box, so that they cannot be tampered with; an inside view of the cover of this box is shown above it in the drawing. It is therefore impossible to set the frame on again, until the catch has been disengaged from the notch I, by winding the rack D back again, ready to commence for a fresh set of bobbins.

The general result of these improvements consists not so much in extra production per spindle—although the production is greater for the same velocity of spindles than it was formerly—but in a very

ior quality of work, which enables the attendant to watch a er number of spindles at the same cost. The machines now with much less breakage, and it is no uncommon thing for a set obbins to be filled without a single end breaking.

In well arranged establishments it is now generally admitted that oderate speed of spindles is most economical, and produces the t quality of work with a minimum of waste. In some parts of ncashire very high speeds of spindles are preferred; but that stem, with its attendant waste and inferior work, is gradually giving y to more moderate rates of speed. The well established maxim at "work spoilt in the card room cannot be mended in the spinning" the best guide in this matter.

It is now customary to make very long machines "double geared," mely with a driving part at each end of the frame. The spindles nd rollers are in one continuous line from one end of the frame the other, but each half can be stopped independently; so that, hen an end breaks, only one half of the machine is stopped to piece the broken end, leaving the other half at work. An increase of about ten per cent. in production is gained by this useful arrangement.

For the finer grades of yarn, there are four passages of these machines,—the slubber, the intermediate, the second intermediate, and the roving or jack. These enable the required fineness of roving to be attained without involving excessive drafts: a single draft should in no case exceed one into six.

The Self-Acting Mule.

In its general arrangement the Self-Acting Mule remains as described in 1866, but many very important additions and improvements have been introduced. The self-acting mule of 1866, although effecting the principal operations, left a number of minor ones to the skill of the operative spinner or "minder," and it performed some of its duties in a very imperfect manner. To be in order, we will first refer to mules for spinning medium counts of yarn, and secondly to those required in the spinning of finer counts.

Mules for Medium Counts.

The first improvement to be noticed is that the governor for regulating the position of the quadrant nut has been ı once exceedingly sensitive and very reliable, and is now suit either coarse or fine counts.

The Backing-off Motion.—This has been perfected, its o being regulated automatically to suit the position of tl at every stage of their progress, from the commencer winding to the completed full cop. Formerly this appara imperfectly manipulated by the minder. The copping a is now used as the controlling agent for regulating this Fig. 7, Plate 74. It is made with a separate front "incli which is loose, and is governed by an additional front c plate E. Formerly only two points in the copping were capable of being adjusted to the exact positions re whereas by the use of the loose incline D all the positi now regulated. The advantage gained by this latter arra is the power of regulating the precise position of the fall when the "faller" is locked—a very important considerati the hand mule, when the spinner had depressed the faller proper position for winding, and uncoiled the exact amount from the bare spindles, he arrested the operation of backing commenced' the winding-on. In the self-acting mule w copping rail in one solid piece, this important object coulc attained. The amount of inclination in the front incline was det by the conditions required to commence the cop on the bare s At the commencement it was very important to keep the "cl the cop or height of the cone, as shown by the close dotted A B in Fig. 8, as short as possible, in order to prevent v unwinding in the subsequent processes. When the copping set at the commencement of the cop, the position of the fall was determined, and set to suit the requirements of the operati as soon as the winding part of the copping rail assumed tl inclined position to enable it to wind a longer chase, then tl incline assumed a less inclined position, leaving the faller wi

time of the faller locking in a worse position at each successive draw, until the chase had attained its maximum at C D, Fig. 8, and had begun to be gradually shortened again. This was in reality a complete reversal of the practice in the hand-spinner's operations. For many years this method was considered quite satisfactory; but the demand for longer cops, built more firmly, gave the impulse to the present improvement. The front incline being now made movable, its position can be regulated so that the operation will be an exact counterpart of the hand-spinner's work, when he made his best cop; and by the use of an automatic apparatus for tightening the backing-off chain, in conjunction with the loose incline D on the copping rail, the amount of yarn uncoiled from the spindles is regulated to suit the position of the faller wire at the termination of the backing-off. When once set, this apparatus needs no attention from the minder.

As the copping motion was explained at length in the former paper, and as the principle is exactly the same, it is unnecessary to describe it beyond what relates to the loose incline, Fig. 7, Plate 74. The copping rail A A rests at one end on the front copping-plate B, and at the other on the back copping-plate C. One end of the loose front incline D is jointed to the "ridge" of the copping rail by the pin F, and its front end rests on the additional front copping-plate E, which is fastened to the copping-plate B in such a manner that it can be adjusted to suit the requirements of the loose incline D. By varying the form and position of the additional copping-plate E, the loose incline D can be regulated to give any required results.

The diagram shows the faller-locking arrangements, with the lock at the bottom of the lever R, Fig. 7, instead of, as in the former arrangement, at the top. The principle is the same in both systems, the alteration being made to suit the requirements of the other parts of the headstock, connected principally with what are technically called the "changes."

The Backing-off-Chain Tightening Motion.—Before explaining the parts connected with this motion, it may be desirable to give some further explanation why this regulation is required.

When the carriage G, Fig. 7, Plate 74, is coming out, o
outward run, the front or winding faller wire is generally abo
above the points of the spindles S. This is also the positio
parts, in ordinary mules, immediately before the operation of
off the spiral of yarn that is coiled upon the bare spindles a
top of the cop. As is well understood, the reversal of the
causes it to uncoil this yarn from the spindles, and als
into action the parts which pull the faller wire down. In
the spindles begin to uncoil before the faller wire begins
because the tin roller must make some little movement bef
backing-off click or pall can take hold of the ratchet whee
addition to this, the spindles continue to uncoil the yarn duri
time the faller wire is moving from its position above the s
points, until it touches the yarn. From this it will be seen
considerable length of yarn will be uncoiled from the spi
before the faller wire can overtake the yarn. The spindles thu
the start very considerably, and at the completion of a set o
this loss of motion of the faller wire produces the worst resul
the case of a cop with its nose, or point, only $\frac{3}{4}$ in. from the
points, the loss is nearly one-half the entire motion of the fall
which moves as far before it touches the yarn as it does aft
overcome this difficulty, it is necessary to have the backing-
tight, so that it may act on the faller as early as possible;
backing-off snail is made as large as possible and of the pro
so that the faller wire may act on the yarn at the earliest m

At the commencement of a set of cops the condition
much more favourable; for, although the space actual
through by the faller wire, before it touches the yar
constant, it bears at the commencement a very mu
proportion to the entire distance passed through by the
the faller locks, than it does at the completion of the
Consequently the backing-off chain has to be slack at t
of a set of cops, otherwise the speed of the faller wire
the yarn down the spindles faster than it would unco
thereby break the thread. Hence, the backing-off
been adjusted to the proper length for backing off

commencement of the set of cops, it is desirable gradually to tighten or shorten it, as the cop increases in length; until at the completion of the cop the chain is almost tight. By this means the backing off can be adjusted all through the set, so that it corresponds at every stage with the exact requirements of the case; the nose of the cop is preserved in a properly firm condition, and neither too much nor too little yarn is uncoiled. Next to winding the yarn properly on the cop, this is the most essential condition in making a good cop. Where the apparatus now to be described, which effects this automatically, is at work, it is found that very much fewer noses, or points of cops, are "halched," or entangled.

Referring to Fig. 7, Plate 74, the winding faller shaft I has keyed upon it the backing-off finger H; the backing-off chain J is fastened at one end to the finger H, and at the other end to the backing-off snail K, which is mounted with a ratchet-clutch upon the tin-roller shaft. The backing-off tightening chain L has one end fastened to the boss of the snail K, and the other end to the bell-crank lever M, the tail of which is shown resting on an incline N. This incline slides upon a plate fastened to the floor; and an arm on the front end of the incline grips the copping-plate connecting-rod P, so that, by means of two hoops fixed upon the connecting-rod P by set-screws, the incline N is caused to move backwards with the backward motion of the rod during the formation of the cop.

In Fig. 7 are shown the positions of the carriage G and the various parts just previous to the time of the backing off taking place, at the commencement of a set of cops. The backing-off chain J having been adjusted to the proper length for backing off on the bare spindle, the copping plates B and C with the connecting-rod P will gradually move inwards or backwards in the direction of the arrow as the cop progresses, and will carry the incline N with them in the same direction. This movement gradually brings the higher part of the incline N under the tail of the lever M, causes it to turn in the direction of the arrow, and so pulls the chain L; which in turn, acting on the snail K, takes up the slack of the backing-off chain J. The incline N is made so that it can be varied to suit the particular requirements of various kinds of mules. The absolute

amount of tightening depends upon the setting of the incline the difference of level between its two extremities; and the tightening at different parts of the incline depends upon the its outline. By varying the form of the incline the actior chain can be varied to suit any circumstances.

When once set the apparatus needs no further attention. commencement of a new set of cops the copping plates B wound forwards again into the position shown in Fig. 7, the i goes with them, and the backing-off chain J is restored to it slackness.

The Automatic Nosing Motion.—An important addition mule in late years is an improvement applied to Richard quadrant winding apparatus. In Roberts' quadrant, as first int and as described in 1866, the only variation in its action, wl set in proper position, was caused by the quadrant nut E Plate 75, being gradually traversed outwards from the centr quadrant, to suit the increasing diameter of the cop, until t attained its full dimension at CC, Fig. 8, when no further mod was made. Now if the spindles had been of equal tl throughout, the winding on would have remained in all it equally good: but this is not so; the spindles are taper.

The function of the quadrant is to accelerate the vel the winding motion, and this constitutes its special merit amount of this acceleration begins at zero, the quadrant nu then nearest the centre of the quadrant; and the velocity governed by the distance of the quadrant nut from the centr increases during the building up of the cop, until it arrives at diameter. The acceleration thus conforms very nearly to requirements of winding. When the cop arrives at its full d CC, Fig. 8, the nut has reached the outer extremity of its tra the quadrant, and no further alteration in its position taken there is therefore no further alteration in its velocity ratio the building up of the remainder of the cop above CD.

But as all cotton mules have taper spindles, it was soo that the cop noses F, Fig. 8, could not be wound tight; a

longer cop requires a longer and stronger spindle and therefore an increase in the amount of taper, the points of the spindles being always of the same diameter, this difficulty has increased as the spindles have been made longer. To put this more clearly, it will be well to describe more fully the requirements of the operation, and what has been done since Roberts' time to meet this difficulty.

The winding parts of a mule should be made so that when the quadrant nut E, Fig. 9, Plate 75, is at the bottom of the quadrant (that is, nearest its centre), the mule can wind the first stretch of yarn on the bare spindle, as shown at A B in Fig. 8, without either leaving yarn uncoiled, or winding it on too tightly, and so breaking it. This is the ordinary condition; for special cases, such as when winding the yarn on paper tubes &c., this rule is departed from; but this does not affect the purposes of the explanation. As the cop bottom increases in diameter from A to CC, Fig. 8, the quadrant nut is moved out further from the centre to suit it; thereby decreasing the speed of the spindles when they are winding on the larger diameter of the cop, but imparting the full terminal speed to them when the carriage completes its inward run and the winding reaches the nose of the cop. In Roberts' quadrant this final speed was nearly the same as the velocity when commencing on the bare spindle. Now the blade or winding part of a cotton-mule spindle tapers from about $\frac{1}{3}$ in. diameter to $\frac{1}{16}$ in. diameter; and as it is necessary in a well-built cop to wind the nose of the cop in all its stages equally close and firm, it follows that the winding must be gradually modified, so that the velocity of the spindles at the termination of the inward run of the carriage shall be suited to the diameter of that part of the spindle on which the nose is being formed: that is to say, the terminal velocity of the spindles should increase in the same ratio as the diameter of the spindle decreases. When first brought into action, this acceleration, or "nosing" as it is called, takes place almost at the termination of the inward run of the carriage; and begins a little earlier in each succeeding draw or run, until at the finish of a set of cops the nosing may begin five or six inches from the end of the inward run of the carriage. If the nosing begins too soon, the yarn is wound too tightly on the part not

requiring additional firmness, and is unduly stretched. This is ve
plainly shown by the action of the counter faller, which in that ca
is pulled down almost close to the winding faller, and then, when t
nosing is required, is seen to rise again, instead of remaini
stationary throughout as it ought to do: such an action is m
injurious to the yarn.

To meet these requirements many contrivances have been inven
during the last fifty years. The one most generally in use is t
called the "Nose Peg." This nose peg, acting on the winding ch
F, Fig. 9, Plate 75, deflects it from a straight line into a bent l
causing additional chain to be uncoiled from the winding-on drum
and consequently increasing the velocity of the spindles. T
although an improvement, imparts but little acceleration, and
little it does begins too early; say about 18 in. from the end of
inward run of the carriage. Various forms have been given to
nose peg, but all amount to the same thing in practice.

The next important improvement was brought out in 1863,
consists in converting the nose peg bracket into a swing lever mou
on the quadrant. By giving this lever a movement on its centre
action on the winding chain is quickened, the acceleration of s
is greater than it is with the fixed nose peg, and its action
therefore commence much later. But the nosing, even with this sw
lever nose peg, still commences too early, is limited in action,
appears to lose its accelerating function when it ought to be grea
This is true of all nose pegs, whether worked by hand or self-ac

Nearly all nosing motions invented during the last fifteen y
have been modifications of the swing-lever, and all except the sc
drum nosing motion are chain-deflectors.

But what is wanted is something which shall continu
supplement the ordinary velocity-accelerating function of
quadrant, so that its action will be suited to the const
diminishing diameter of the spindle on which the cop nose is b
wound. This object is attained by the application and use of a s
upon the end of the winding-on drum H, Fig. 9, Plate 75.

When the cop has attained its full diameter CC, Fig. 8,
scroll drum H should be in the position shown in Fig. 11, Plat

on the completion of the inward run of the carriage G. As the cop becomes gradually built up higher on the taper spindle, more winding chain ought to be uncoiled from the scroll, until, at the completion of the cop, the chain should be wholly uncoiled, as shown in Fig. 12. It will be understood that the velocity of the winding increases in the same ratio as the diameter decreases of the scroll H from which the chain is uncoiled. The amount of acceleration thus given depends on the quantity used of the scroll portion of the winding drum: and the character of the acceleration depends on the form of the scroll end of the winding drum. Its range of acceleration is very much greater than that of any other apparatus yet invented.

Fig. 9, Plate 75, shows the position in which the parts should be placed to commence with. The quadrant is shown in the position in which it stands when the bowl is on the ridge of the copping rail. The carriage G is shown in the position when it has made about 12 in. of its inward run.

Fig. 10 shows the quadrant nut E, with the parts on it in the same position as shown in Fig. 11, Plate 76, that is, when the cop bottom has just been completed. The carriage G, Fig. 11, is shown close up to the back stops. The quadrant nut E is in its final or extreme outermost position for making the rest of the cop. The arrow across the winding-on drum H is in the same position as shown in Fig. 9; that is, the chain F has been uncoiled from the cylindrical part of the winding-on drum, until it is on the point of uncoiling from the scroll part. The arrow-head crosses the drum where the cylindrical concentric part ends and the scroll begins.

Fig. 12, Plate 76, shows the position of the parts on the completion of a set of cops. It will be observed that the winding chain F is here uncoiling from the small end of the scroll H.

The end of the winding chain F, Fig. 9, Plate 75, instead of being merely attached as formerly to the quadrant nut E, is now wound upon the body of a ratchet-wheel A, on the shaft of which is also fixed a scroll I. Another chain C, coiling on this scroll, passes thence under and over the stationary pulleys B and D, and under the swinging pulley K; and its end is fastened to the sliding

bracket L, which slides on the shaper screw M of the coppin
The pull of the chain C causes this sliding bracket L
outwards against the front nug of the shaper frame whic
the shaper screw M. The shaper screw is turned as usu
ratchet-wheel R, which is moved through one tooth at each
quadrant by the wire Q. The nut N, travelling in toward
the shaper screw, comes into contact with an inner arm on th
L, as shown in Fig. 11, Plate 76, and causes it to slide inw
the inward movement of the nut, and so gradually pulls th
in the same direction. The inner arm on the bracket L
adjustable for the purpose of regulating the time when the
the shaper screw shall come into contact with it. The
pulley K is carried at the bottom extremity of the lever P
from the centre D; and on the lever is centered an arm S fr
upwards but not downwards. A bracket T upon the qu
capable of pushing outwards the lever P by means of th
when the quadrant is rotating outwards. The steel en
winding chain F, which goes into the quadrant nut E, is
long. The remainder or curb part of the chain will the
shorter than usual, and does not enter into the quadrant
and thus escapes the wear it would otherwise incur in passi
the small anti-friction pulley at the bottom of the nut E.

The parts being properly adjusted, the mode of work
follows. After the first stretch, the governor motion from
time moves the quadrant nut E further out from the cen
quadrant, so as to adjust the winding to the increasing s
cop. By this movement of the quadrant nut the slack in
C is soon taken up; and after the slack is taken up, th
outward movement of the quadrant nut causes the chain
the bottom of the lever P inwards. On the return or out
of the carriage, the bracket T, acting on the arm S, forces
P outwards again; and in so doing pulls a length of chai
the scroll I, thereby causing it to turn on its axis and wind
ratchet-wheel A a length of winding chain F, which would
remain coiled on the winding-on drum H: the ratchet-
caught by one or other of two detent catches which enter

teeth. In consequence of the ratchet-wheel in the quadrant nut thus taking up at intervals a length of winding chain about equal to the increasing distance of the nut from the quadrant centre B, the length of chain left coiled on the winding drum H at the end of each inward run of the carriage will remain nearly the same, until the cop has attained its full diameter, when the parts should be in the position shown in Fig. 11, Plate 76, the nut E having then reached the furthest extremity of its travel along the quadrant arm. Till this stage the sliding bracket L, Fig. 9, will still remain pressed outwards against the front nug of the shaper frame. About this time the nut N on the shaper screw will come into contact with the sliding bracket L, as in Fig. 11, and will gradually draw the bracket inwards, together with the chain C and lever P; it will thus draw a further length of chain C from the scroll I, wind up a further length of winding chain F upon the ratchet-wheel A, and cause the chain F now to unwind not only from the cylindrical, but also from a portion of the scroll part of the winding-on drum H. The repetition of this action gradually brings more and more of the scroll part of the winding-on drum H into use: until at the completion of the set of cops, Fig. 12, as much of the scroll part has been brought into use as the circumstances of the case require. By causing the nut N of the shaper screw to act sooner or later on the sliding bracket L, a greater or less amount of the scroll on the winding-on drum H may be brought into use. By these arrangements the winding can be accommodated to any form of spindles. On the completion of the set of cops, the scroll I on the quadrant nut E should be in the position shown by the dotted lines in Fig. 9, at the top extremity of the quadrant arm. Before beginning a fresh set of cops, the winding chain F must be uncoiled from the ratchet-wheel A in the quadrant nut.

A further improvement in the winding motion has been effected by a change in the manner of engaging the click with the click-wheel on the shaft of the tin roller K, Fig. 13, Plate 76. Formerly the movement of the carriage G at the commencement of its inward run, by means of the winding chain F, drum H, and spur wheel and pinion, caused the loose click-plate carrying the click-

and as the winding always finishes at th
wound on the spindles in some runs than
objectionable, because the yarn would b
"snarls," when the winding commenced lat

To remedy this defect, the click L, F
before the carriage G actually begins
simple contrivance: consequently the s
imparted to the spindles in each inward ru
its full thickness, except what is gained by
nosing motion, as already explained. In th
was engaged by the click moving round
the moment was stationary. In the new
put in motion, whilst the click is station
thus the converse of the other. For th
which the click-spring rotates, instead of
of a fixed bracket, is now the centre boss
loosely on the shaft of the tin roller K
lever is actuated at the proper time by a fin
rod R which lifts the "holding-out catch
motion from the "taking-in lever," as it
into gear; and by means of the lever an
gear with the click-wheel; this stops th
moving inwards the winding on comm

carriage, in the same manner as at the middle of the headstock and at the out-ends of the mule, except that for convenience the bands are here passed under the carriage. By means of these bands the carriage is now governed at five points in its length.

Another important improvement in the back shaft is the connection between it and the shaft of the taking-in scroll. Formerly the carriage was pulled in from the headstock only, that is to say, from the middle of its length only, and the ends of the mule were kept something like parallel with the middle part by means of squaring bands. By connecting the back shaft, when the mule is going in, with the taking-in scroll shaft, by means of extra scrolls and bands, the back shaft receives a motion exactly similar to that imparted to the middle of the carriage. It is converted into a taking-in as well as a drawing-out shaft, and the motion of the carriage is kept steady by six bands, instead of two as formerly.

The cam shaft of the headstock still retains its important position as one of the main features of the self-acting mule. In its best form it is worked by a friction box, which permits of the quickest velocity of rotation, and at the same time, whilst it is sufficiently positive or unyielding for the work it has to perform, is not liable to break the rigidly connected parts in case of derangement. For medium counts it is now almost universally used with two changes; the other changes in the action of the mule being effected without its intervention. Thus the two former systems are combined—namely, that system in which all the changes were made by the cam shaft, and that in which no cam shaft was used. The great desiderata are reliability and rapidity; and these have thus been attained to a remarkable extent, yielding a regularity of production unknown in former periods.

The general parts of the mule have been much strengthened. Rim shafts now revolve at as high an average speed as 650 revolutions per minute, driven by 4 in. and 4½ in. belts. The pulley being 15 in. diameter, or 3·92 feet circumference, this gives 2,550 feet per minute as the speed of the belt; and in some cases it is even higher than this.

The backing-off, taking-in, and cam friction-clutches have been enlarged to give them greater controlling power. The rods, levers,

revolutions per minute, with cops on the
than those formerly made.

Mules, as machines, now work very
quietly, and are far less subject to stoppag
before; whilst their capacity to stand the
of work produced is very much greater.

The present construction may be exp
than any previous to 1866. The produ
1866 was given in the former paper as 2
week, but some of the best mills were
The present production of a modern mill,
per week, is fully 27 hanks per spindle fo
increase of at least 3½ or 4 hanks per spin
reduction in the time worked is really gre
it was formerly the custom to clean the
had stopped, whereas now it is usual to cle
The actual increase is equal to about 14
account the reduction of time, 6·6 to 7
production is equal to about 22 per cent.
yarn spun has improved from 8 to 10 per c

The size or length of mules remain
number of long mules now working has ve

The number of workpeople requir
containing say 2000 spindles is the same

The great velocity now given to the rim shafts has caused the line shafts of spinning mills to be driven very much more quickly; formerly 180 to 200 revolutions per minute was considered a good speed, but with quicker rim shafts a speed of 240 to 250 revolutions is now desirable, so as to avoid the use of large drums on the line hafts, and also of large drums and small pulleys on the counter-afts. Nearly all mules are now driven by counter-shafts.

The difficulty of obtaining these high velocities by direct driving s led to the introduction of belt and rope driving in many of the ton mills recently built; and the results are very satisfactory, a adier motion being imparted to the machines. The adoption of belt l rope driving has also been influenced by the number of breakdowns the mills built during the last seven years, where gearing was used. doubt the greatly increased production of the machines has had ch to do with these accidents. Where rope or strap driving has been introduced, cast-steel wheels have been generally substituted the broken cast-iron ones.

For spinning yarns of medium fine counts, say up to No. 90, the f-acting mule has now almost entirely superseded the hand mule. e mule just described is used for the purpose, but it is supplemented a jacking motion, and a roller delivery motion. The work oduced is excellent, both in quality and in quantity.

Jacking Motion.—This continues the outward run of the mule riage after the rollers for drawing the cotton have ceased to volve, in order that any thick places occurring in the yarn y be made uniform with the rest; its effect being that, wherever ere is a thin place in the thread, the greater portion of the twist ns into that part first, and thereby renders it more difficult to be ngated than the thicker parts, which are thus drawn down. e amount of jacking introduced varies from zero to 4 or 5 , according as the staple of cotton to be spun is shorter or ger, the longest admitting of the greatest amount of jacking. rious systems have been applied for this purpose, but that known the "sun and planet" system is undoubtedly the best, as the ppage of the rollers is more gradual by this than by any other.

Roller Delivery Motion.—As little twist as possible is put the yarn before the jacking commences, only just sufficient to the fibres united; therefore a great amount has to be put in afte rollers have stopped. This has the effect of tightening the yarn, unless the tension is reduced the yarn is liable to break befor required amount of twist has been put in. Formerly it was custo to cause the carriage to move inwards a little, in order to ease tension of the yarn; this had the desired effect, but it shortened stretch, and the carriage being a large apparatus was difficu regulate. Now, instead of moving the carriage, the rollers are to revolve, and to deliver a small quantity of roving at a rate w can be varied at will, whilst the extra twist is being put into the y and the result is very satisfactory. This apparatus is called "roller delivery motion whilst jacking."

It is also customary to cause the rollers to deliver a little during the inward run of the carriage, whilst the spun ya being wound on the spindles. The amount varies from 3 to 4 in consequently a mule of 60 inches stretch will wind on the sp at each stretch about 63 inches of yarn. The apparatus for purpose is universally used when spinning long stapled cotton, the spinning is greatly improved thereby. Time does not p to explain this more fully, or to enlarge on the drawing rolle mules, and the varieties of spindles suitable for these special ya

Mules for Finest Counts.

For spinning the finest counts of yarn the hand mule has brought to great perfection; all its operations being now autom or nearly so. The "spinner," as he is called, has only to suppl little power required to control some of the motions. This he i to do easily, even when the mules are large; but it requires close attention on his part, coupled with an extremely sensitive t which can only be acquired by long practice. To back off, wind lift the faller at the termination of the inward run of the carria first-class style, demands great skill on the part of the operator. work being done in hot rooms increases the difficulty, and almost impossible for him to work uniformly from morning till

of first-class ability as spinners become scarcer year by year; the necessity of reducing the cost of spinning has called special ntion to the question of making this mule entirely automatic. ing the last 25 years many patents have been taken out, and y schemes have been tried, but the general results have been unsatisfactory; the methods were generally of too provisional aracter.

The limits of this paper only admit a description of one system, ich has been extensively adopted. The aim of the inventor has n to imitate the action of the hand spinner in every delicate ration, as far as "positive" mechanism could be made available.

Description of the Mule.—The hand spinner, when backing-off, ngs the winding faller down upon the yarn, before he reverses spindles so as to uncoil the yarn from them; and the moment faller touches the yarn, both motions act together. To obtain this ult with the self-actor, the winding faller I is depressed by the arm and incline T, Fig. 14, Plate 77, just before the carriage G npletes its outward run. At the same time the slack in the backing-chain J, caused by this movement, is taken up by a modification the apparatus used for regulating the backing-off chain, in the f-acting mule for medium counts, as previously described. The cking-off snail K, chains J and L, and bell-crank lever M, remain shown in Fig. 7, Plate 74. But instead of the tail of the lever bearing as before upon the sliding incline N, it is here made to ar upon an inclined arm U hinged to a stationary bracket, and it the free extremity of this arm which bears upon the sliding incline . The elevation of the arm U is thus gradually increased as the cline N is traversed inwards by the copping-plate connecting-rod so that it may give the exact amount of tightening motion quired for the backing-off chain J at each stage of the cop's ogress. In order further to modify the backing-off, so that it may suited to the form of the spindles, the eccentric pulley V is troduced, and the backing-off chain J is divided into two half-ngths: the upper half coils upon the boss of the pulley V, while other half, attached to the backing-off snail K, coils upon the

eccentric rim. The depression of the winding faller I is uniform all through the formation of the set of cops; but the position of the locking lever R and its parts is constantly varying within small limits, and the compensation required to meet the variations is provided for by this modification of the motion previously described. By these means a very delicate action in the backing-off is obtained. The finer the counts of yarn to be spun, the slower is the velocity of the spindles when backing off.

The yarn having been backed off from the spindle, and the faller I locked, it is now necessary to wind the yarn on the cop, beginning at the point or nose and winding it down to the base of the cone, in preparation for winding upwards again from the base of the cone to its point. A special apparatus has been introduced into the quadrant motion, to perform this operation in the fine-spinning mule. It must be explained that fine yarns are generally doubled after being spun; and for this purpose the cop is mounted on a steel skewer, and placed in the creel of a doubler, in a slightly inclined position, free to turn in the creel and allow the yarn to be uncoiled from the skewer. When the yarn is unwinding from the small part of the cop down to its full diameter, the action goes on all right, because there are many turns of yarn to uncoil, and the cop gradually turns on its axis more slowly as the diameter increases. About 50 inches of yarn are uncoiled by the time the full diameter is reached; but in uncoiling the next 10 inches of yarn there is a rapid increase in the speed of the cop, in consequence of returning so quickly in a few coils from the full diameter to the small diameter at the nose of the cop. This causes the cop to be jerked round too quickly: it then overruns itself and is very liable to break the yarn. The hand spinner can regulate the number of coils at pleasure, and in practice it is found that about 6 coils in the height of the cone are sufficient to prevent the cop from being jerked round too quickly when afterwards unwinding in the doubler; but to obtain this result by self-acting means is very difficult, and only one solution has been found for it.

The quadrant motion, as originally used, is capable of giving an accelerating motion only; but the true requirements of the case

demand that the motion shall be first a diminishing and then an accelerating one, because the winding in each stretch commences on the smallest diameter, then winds down to the largest diameter or base of the cone, and then upwards again with close coils to the smallest diameter or nose. In practice however this has never been fully attained. It is found that by the yielding of the counter faller a compromise is made between the demands of the small and large diameters, when winding down to the base of the cone; and as this is only the initial stage of the winding, no harm is done, because there is compensation enough in the rest of the winding, which is regulated to suit the exact requirements of each stretch. But by the ordinary arrangement of quadrant, after the cop has attained its full diameter it is impossible to wind more than 4½ coils of yarn on the spindle, during the time it is winding from the point of the cop down to the base of the cone. The front incline of the copping rail A, Fig. 7, has been lengthened to 15 in. and in some cases to 18 in. (the inclination being diminished so as to preserve the same absolute rise in the longer incline), under the impression that a greater length of yarn would thereby be wound on the spindles during the putting down of the winding faller. It is not from this however that the defect arises; but simply from the want of a sufficient number of turns in the spindles. If a long incline is used, the result is simply that the counter faller rises very high and takes up the slack yarn which ought to have been coiled on the spindles; but when the spindles receive the necessary amount of motion it is found that 10 or 12 inches length of incline is sufficient for enabling 6 or 7 turns of yarn to be coiled on the spindles during the putting down of the faller.

The quadrant is governed by a grooved rope-drum U, Fig. 9, Plate 75, on the quadrant shaft, this drum receiving its motion from the travel of the carriage G. Ordinarily the drum is a concentric cylinder, so that if the motion of the carriage is uniform, the rotation of the quadrant shaft is uniform, and the angular motion of the quadrant is uniform also. If, at the commencement of the inward run of the carriage, the relative speed of the quadrant, in the same direction, be reduced, it is evident that more of the chain F will be uncoiled from the winding-on drum H, and more motion will be given

be coiled on them during the putting d
By the time the large diameter of the co
to uncoil from the cylindrical part of
modification of the winding motion takes
comes into operation. When once adj
required from the spinner. Old spinne
to attain this result by automatic means

To enable the counter faller to act
yarn, its shaft is now mounted on ant
found to work advantageously. The
yarn on the cop without moving the co
already explained this is impossible i
faller playing a very important part in t

Special arrangements are used in th
faller and counter faller, and in the p
relative to the winding faller; but these

The Winding-Faller Lifting Motion.-
at the termination of its inward run, it is
faller, and then to coil the remainder of
bare spindle, preparatory to commencin
outward run. This is the most importa

the rollers, varies with the counts spun, within well defined limits; the finer the counts, the greater the inclination of the spindles to the rollers, and the more obtuse therefore the angle made by the spindle and thread just at the commencement of the outward run of the carriage.

The winding on of the yarn during the run-in of the carriage equires to be regulated so that at the end of the run-in just ufficient yarn is left to coil on the bare tops of the spindles, without ither stretching the yarn, or leaving it slack to run into snarls. 'his is the problem to solve. The spinner, having regulated the inding during the run-in, so that the proper amount of yarn was ft to coil on the bare spindle, brought the carriage to a standstill, ıd then slowly lifted the winding faller, while at the same time he gulated the winding so that the yarn was coiled on the taper indles. As soon as the faller was free from the yarn, he allowed ıe carriage to start on its outward run for another stretch. He erformed these operations with more or less rapidity according to ıe counts to be spun. On the medium counts the movements llow each other with almost the same rapidity and regularity as ı the ordinary self-acting mule; but as the counts become finer, ıe division of the operations becomes more marked and deliberate. 'his is especially so in the "Box Organ Hand Mule," in which the pinning does not commence until it is set in motion, after the ompletion of the faller lifting. The momentum of the various arts is completely under the control of the spinner, and is ractically destroyed.

In ordinary self-actors the unlocking of the faller takes place luring the run-in of the carriage, but at as late a period as possible. The carriage, when near the termination of its inward run, brings he end of the locking lever in contact with the fixed unlocking racket, and forces the locking lever out of contact with the copping parts of the mule. After the faller is thus unlocked, the copping rail as no further control over it.

It will be understood from the preceding explanation that the nlocking must be completed before the termination of the inward un of the carriage. In determining how late it is safe to unlock he faller, allowance has to be made for the variations in the speed

entirely eliminated. The result is that unwound than is required for coiling on the

In the apparatus shown in Fig. 15, Pl effected in the following way. Instead of being a fixture, as ordinarily used, it is here which is hinged to the weighted bell-crank throw the stop A forwards into the positio arrangements are made for restoring this position, shown dotted, after it has unlocked position for unlocking, as shown dotted, it i also of bell-crank shape; this catch is libe striking against its tail at the proper tim termination of the inward run. The lo connected parts remain as usual. The unlo as shown dotted, so that the carriage can stops without unlocking the faller; but directly forces the unlocking. On the carria which holds back the unlocking stop A, th and throws the stop forwards against the tai and thus unlocks it just as the carriage c By setting the catch C to be liberated sooner the faller can be unlocked at the proper found that the rollers and carriage motions another stretch, before the faller I has lifte

acquired by the spindles during the run-in of the carriage, the faller wire being raised quickly out of the way by the lifting springs The results are very irregular; sometimes snarls are wound on, and sometimes the yarn is stretched, or "cut" as it is called. In the arrangements illustrated in Fig 15, Plate 78, the tin roller K which drives the spindles S is connected with the faller shaft J positively, by a train of gearing, so that the tin roller controls the motion of the faller during its rise. The relative motions of the tin roller and faller are not always the same. The motion of the tin roller being assumed as uniform, the motion imparted to the spindles will be uniform also; but in order that the yarn may be guided so as to coil nicely on the bare spindle above the cop, it is obvious that the faller wire must rise most quickly when winding on the largest diameter of spindle, and the rate of rising must gradually diminish as the spindle decreases in diameter towards the top, thus producing a tapering spiral of yarn on the spindle. To obtain this result a pair of volut wheels are employed, which convert the uniform motion of the tin roller K into a variable motion of the faller shaft J.

This connection of the tin roller and faller shaft must however be continued only during the lift of the faller; because the tin roller, first set in motion to turn the spindles for lifting the faller, continues in motion during the whole of the outward run and until the backing-off takes place; whereas the faller must stop rising almost immediately it has coiled the yarn up to the top of the bare spindle.

The following is accordingly the mode of action. A hollow friction cone D, Fig. 16, Plate 78, is keyed fast on the shaft of the tin roller K. Loose on the same shaft is a solid friction cone, covered as usual with leather, and capable of being slid along the shaft into and out of gear with the fast cone. Cast to the loose cone is a pinion J, gearing into the carrier wheel E and having a deep flange cast on its outer end; its teeth are also wider than the teeth of the carrier wheel E, to allow of its sliding far enough for disengaging the loose cone from the fast one. On the outer side of the carrier-wheel rim is cast an inclined cheek T, capable of bearing against the inside of the flange on the pinion J and so drawing the loose cone out of gear. This pinion has also a groove cut into its boss, into which fits the fork

of the engaging lever F, weighted with a counterweight, which alway tends to slide the loose cone into contact with the fast one, and s engage them together. Now it will be obvious that the lifting motio should be brought into action immediately the faller has bee unlocked. If it were put into action too soon, one motion wou be acting against the other, and a breakdown would be the resul and if too late it would be useless. To ensure both motions worki in harmony, the unlocking of the faller is made to liberate t weighted engaging lever F, and thus allow it to put the friction con into gear. This is accomplished by means of the connecting-rod H which forms a lock for the end of the connecting-rod L, the latte being coupled to the weighted engaging lever F. The two rods wor at right angles to each other. On the unlocking of the faller at th end of the inward run, the connecting-rod H, which is worked from the faller lever R, is pulled forwards in the direction of the arrow until it releases the stud on the other connecting-rod L, and s liberates this rod and the weighted lever F, which at once throws th friction cones into gear. As soon as the friction cones are in gea the faller I begins to be lifted, motion being communicated to it the proper ratio from the tin-roller shaft K by the volute arcs N By the time the faller is lifted clear of the yarn and its work do the inclined cheek T on the side of the carrier wheel E has begun bear against the flange of the pinion J, and, forcing it outwards by wedge action, draws the friction cones asunder, and thus severs t motion from the tin roller to the faller. This action is a ve beautiful one.

Self-stopping couplings to the cam shaft are common, but the stop during less than a revolution of the shaft. For the abo purpose the stopping must be effected anywhere between a part of revolution and three revolutions or more: no two draws are ali since, as the cop is built up, less and less of the spindle is left ba and therefore the faller has to be lifted less, and the lifting moti must be disengaged earlier. By setting the inclined disengagi cheek T of the carrier-wheel E so that the disengagement takes pla immediately the faller has risen clear of the yarn, it is always saf The arc through which the faller has to be lifted is comparativel

say about 80° when beginning a set of cops, and becomes
lly less until it is only about 30° on the completion of the cops.
en the spindles are backing off, the putting down of the
g faller by the backing-off chain reverses the train of gearing,
noves the inclined disengaging cheek of the carrier-wheel E
ntact with the flange of the pinion J. This action would allow
ction cones to be thrown into gear again by the weighted
', if not prevented by a stop M, Fig. 15, which holds up the
'. The carriage G, when near the termination of its outward
ings a part of the lever F against the stop so as to be held
The greater the arc of motion of the faller during the backing
greater is the motion of the carrier-wheel E, the further is
ined cheek T upon it removed from the flange of the pinion J,
e more revolutions are made by the pinion. Whether the
moves through a large or small arc therefore, it is always
d from the control of the tin roller at the proper time. The
operation occupies only about one second. It is the short
llowed which forms one of the difficulties of this difficult
n.

e stop M, Fig. 15, which keeps the friction cones D out of gear
the backing off, keeps them so until the lock R of the faller,
the connecting-rod H inwards, locks the connecting-rod L,
ained before, and so holds up the weighted engaging lever F.

other important feature of this operation is the speed at which
rts are allowed to work. The speed of the spindles, at the
ation of the inward run, is too quick to allow of the use of the
e gearing already described, as it is found impossible to engage
rts sufficiently quickly. This difficulty is further increased by
ndles being quickened to the spinning speed directly the carriage
s its inward run; for it is impossible to rely on the momentum
spindles for continuing their rotation during the lifting of the
the results being too variable. To overcome this difficulty,
a driving belt, called the "taking-in" belt, is used for driving
f-acting pulley; this belt has generally about half the speed
main rim-shaft belt, both belts working on pulleys of the same

diameter on the rim-shaft. Fig. 17, Plate 77, is a plan headstock carrying the main driving or rim-shaft R. The driving belt runs on the fast pulley A and loose pulley B, while C D are the fast and loose pulleys for the slower belt; both receive their motion as usual from the counter-shaft S, Fig. 18.

The cam shaft has three changes in this mule. When the carr is making its outward run, the quick belt is on its fast pulley A, the slow belt is on its loose pulley D. At the proper time the shaft makes its first change, the rollers are stopped, and when proper amount of twist has been put into the yarn, the twist mo disengages the catch which holds the quick belt on the fast pulle and allows a spring to shift it on to the loose pulley B. This allows backing-off to take place in the usual way; after which the carria caused to make its inward run, and just before the termination cau the cam shaft to make a second change, and shifts the slow taking belt on to its fast pulley C, whereby the rim-wheel W is then driv at a comparatively slow rate. It is whilst this slower speed has t control of the mule that the lifting apparatus does its work. T slower belt when first shifted to its fast pulley acts as a kind brake on the momentum of the rim shaft R, and can be relied up to give the same retardation in every stretch. When the windi faller has lifted nearly clear of the yarn, a finger on it comes contact with the cam shaft escapement, and allows the cam shaft make a third change, which shifts the slow belt back from its f pulley C to its loose pulley D, and then shifts the quick belt on its fast pulley A, causing the spinning to go on at the proper spe So rapidly is the whole operation performed that it is impossible see the change in speed from the slow to the quick belt, though course it is easy to see the movement of the belts from one pulley the other. The slower the operation, the more perfectly is it do but it is found to be well done with spindles running at 1, revolutions per minute.

During the outward run of the carriage the various parts replaced in their proper position for effecting these operations.

An apparatus is also used by which the winding faller, du the time it is being lifted, is enabled to govern the counter f

such a manner that the counter faller is free to take up the slack arn, if any, made during the rise of the winding faller, and is epressed below the yarn, as usual, before the spinning commences gain.

"Double speed" motions are still used for the finest counts; but as this element would render the previous explanation more complex, it has been purposely omitted.

Ring Spinning.

In conclusion, it is necessary to allude to the question of Ring Spinning. Of late years considerable attention has been given to this subject, and many machines for the purpose have been set to work in this and other countries. In America it has long been in use. The best type of spindle in these machines is the outcome of American experience, the most popular being the "Rabbeth" and "Booth Sawyer."

Ring spinning has generally been substituted hitherto for fly throstle spinning, to which it is more closely allied; but in some cases it is competing with mule spinning, although to a very limited extent on account of its winding on wood bobbins. It is only suitable for medium counts, and requires good cotton to give the best results. It produces a stronger yarn than the mule, but not so strong as the throstle; nor is it so universal in its application as the latter. Further experience is necessary before it will be safe to say what is the proper position of the ring-spinning throstle in the economy of the cotton trade. At present opinions differ very much indeed on the question; and as to durability there are no data from which comparisons can be made with other competing machines.

The writer has now only to express his great indebtedness to Mr. John Dodd, of the firm of Messrs. Platt Brothers and Co., for the preparation of this paper, and to the same firm for the drawings.

The PRESIDENT proposed a hearty vote of thanks t Spencer for his elaborate and excellent paper; and also f important series of drawings, which would all be carefully repr in the Proceedings, and would give very valuable information members. He had thought, with regard to an industry li cotton manufacture, occupying as it did hundreds of thousa hands, that it would be a reproach to the Institution if the m had not the best and latest information on the subject; he had to headquarters for it, and the Institution had now been su with the information in the most liberal manner by Mr. Spence the assistance of Messrs. Platt Brothers.

Mr. SPENCER said he had only to add that in preparing the he had had the assistance of several other gentlemen; and ha obliged to rely on them to some extent, as he had himself been so out of health during the past year, so that a great portion paper was not really his own. He had however done his compiling it, and he was glad it had received approval; but sure the meeting would include these gentlemen also in the thanks.

The vote of thanks was passed unanimously.

The following paper was then read:—

ON IMPLEMENTS AND MACHINERY FOR CULTIVATING LAND BY HORSE-POWER.

BY MR. W. R. BOUSFIELD, OF LONDON.

The operations of agriculture, so far as they come within the province of the mechanical engineer, may be roughly divided into four groups as follows:—

1. The preparation of the land.
2. The sowing of seed, &c.
3. The harvesting of the crops.'
4. The preparation of the crops for consumption.

The writer proposes to consider in this paper the operations included in the first of these groups, so far as they are effected by implements or machinery worked by horses; and to discuss the construction of these implements and machines, and the conditions to be fulfilled by them for the most efficient performance of their work.

In order that the surface of the ground may be brought into, and maintained in, a condition of fertility for the production of cultivated crops, it must be properly drained, must be periodically stirred and turned over, so that every part of the soil to a certain depth may be exposed to atmospheric influences, must be reduced to a finely divided and porous state, so that the rootlets of the plants may have free scope, and must be from time to time manured, to compensate for the exhaustive effect of the crops produced.

We have therefore to consider:—

1. Implements for drainage.
2. Ploughs.
3. Cultivators.
4. Harrows.
5. Rollers and Clod Crushers.
6. Manure distributors.

1. Implements for Drainage.

The importance of a thorough system of surface drainage but lately begun to be universally recognised. In relation to po soils the subject is of less moment; but, with heavy clay la the different proportions of the rainfall which pass off by pr drains, or by percolation through the underlying strata, or evaporation, are of the utmost importance. Stagnation of water only renders the operations of husbandry more difficult, but absolutely fatal to many crops. Besides this, the loss of heat to an excessive quantity of moisture passing off by evaporation highly prejudicial. In climates such as our own, on the supposit that one fourth of the whole rainfall passes off by evaporation inst of by proper drains, there is a loss of energy over a given s of clay land sufficient to plough it several times; and no doubt important part of the heat thus abstracted would, if the land w properly drained, appear as potential energy in the shape of r and grain.

Various attempts have been made by the mechanical engin to assist the agriculturist in the matter of drainage. The m practically efficient implement is the Subsoil plough, by means which the ground is stirred to a depth of from one to two feet be that at which it is usually cultivated.

When the land is drained by means of a system of pipes l at a depth of from two to four feet, the subsoiler is of g value in opening out a connection between the drain and surface. Perhaps the best plan of subsoiling by horse power is remove the right-hand body of an ordinary double-furrow plou and to substitute for it a strong tine, working at the requisite dep

elow the bottom of the furrow. With this plan the ground is not rodden by the horses after the subsoiler has done its work, but immediately covered over by the next furrow slice. According the method of subsoiling generally adopted, the subsoiler is ounted as a separate implement following in the wake of the dinary plough; but this system is attended with the disadvantage employing two sets of men and horses, besides which the pan the furrow is twice trodden by the team, once before the action the subsoiler, and once after, when the plough comes round again.

Besides the subsoil plough, which, strictly speaking is only an xiliary to the work of drainage, special draining ploughs have en made and used to some extent; the object aimed at being cut a channel of some kind through which drainage may take ace, or in which drain-tiles may be laid. The oldest of these is e Mole plough, which consists of a solid cylinder of iron, pointed the front end, and attached by means of a deep frame to a strong am. The cylinder or mole, being drawn through the earth at a pth of from 12 to 20 inches, leaves behind it a channel mmunicating with the surface by a narrow opening. A series of hese channels is connected by a master drain running transversely. The mole plough can only be used to advantage on stiff clay lands; nd even on these the channels formed by it are not very lasting, or is the system of drainage very efficient. An attempt was made, many years ago, to render the channels so formed permanent, by ausing the mole to draw after it into the bore which it formed a series f drain tiles strung on a wire rope, which was afterwards withdrawn. The machine was worked by two horses through a windlass,* and was apable of adjustment to avoid the inequalities of level in the work, due to the uneven surface of the ground; but the apparatus seems to be of very limited application. In fact the field for drainage implements is so limited, that no great amount of ingenuity has been expended on heir production. Nevertheless an implement which would open out trench from two to four feet in depth for the reception of ordinary rain tiles, in such a manner as to compete with hand labour, would

* See Mr. J. Fowler's Paper, Proceedings 1857, p. 57.

be of great advantage for clay land free from stones. Mr. MacEwen, of Blackdub, attempted to solve the problem by means of two ploughs, having the cutting parts and breast of the requisite form. The first plough was intended to cut out the slice to half the required depth; the second to complete the trench. An attempt has also been made to achieve the object in view by means of a revolving disc carrying a series of cutting scoops, but the writer believes that it was unsuccessful. The problem still waits for a practical solution.

2. Ploughs.

Leaving the question of subsoiling and drainage, we pass on to consider the implement which is the most important of all to the farmer—the Plough. The history of the early development of the plough is a matter of archæological rather than of mechanical interest, and has been treated of by Mr. W. Waller in a paper read before the Institution (Proceedings, 1857, p. 41*). We proceed at once to the consideration of the implement in its modern forms, illustrated in Plate 80.

Although the general features of the plough are the same all kinds of work and in all localities, yet the details of construc are subject to numerous modifications, according to the natur the work required to be done, and to the custom or requirem of the district for which the plough is intended. The essentia the plough are, the *beam* B, Fig. 6, the *cutting* and *turning* of the implement, the *head* H at the front end, through which draught is taken, and the *handle* or *handles* at the other end means of which the implement is controlled.

The beam and handles together constitute a framework, w must be proportioned so as to give to the ploughman the requ command over the implement, and must possess sufficient rig to withstand the longitudinal and torsional strains to which

* The writer has lately seen, at the Roman Villa which has recently unearthed at Brading in the Isle of Wight, a mosaic representation of a pl having the form of a pointed cylinder attached to a hooked handle implement being about four feet long and held in the hand; this, he beli has not previously been described.

subjected. When the motion of the plough is steady, the chief strains tend to stretch the beam and to bend it upwards. By means of the draught-chain the draught may be, and is by some makers, taken directly from the body, the head exercising only a directive influence, and thus the beam is relieved from the tensional strain. But the advantage of the draught-chain is doubtful; as a beam which is strong enough to resist the bending strains and those brought into play in turning at the headland, will be sufficiently strong to bear in addition the tensional strain. There seems to be no good reason therefore why the draught should not be taken directly from the head in every case.

The handles must be sufficiently rigid to withstand an upward or downward pressure or a twisting strain from the ploughman, either in the work of the implement or in turning at the headland. Their height above the bottom of the furrow should be adapted to the stature of the ploughman, and their length to the nature of the work for which the plough is intended.

"The head stands to the plough in the same relation as the rudder to a ship." By means of it the point of application of the draught may be adjusted, both vertically and laterally, so that the plough may be even and steady in its motion, without any tendency to run into or out of the land, the guiding work of the ploughman exercised through the handles being thus reduced to a minimum. Where no draught-chain is used, the head usually consists of a vertical bar, called the *hake*, carrying a series of notches by means of which the vertical adjustment may be given, and capable of being moved about a vertical axis, and fixed in any position upon a horizontal sector of a circle, so as to give the lateral adjustment. Where the draught-chain is used, a rod which can slide vertically, carrying an eye through which the draught-chain passes, takes the place of the hake. In some of the most improved ploughs the lateral adjustment is given with great nicety by means of a transverse screw, working through a block which carries the hake. This nicety is of considerable importance, as a very small alteration in the direction of the draught gives the plough a tendency to swerve from the straight line.

The framework constituted by the beam and handles is substantiall the same for all kinds of work; but the cutting and turning parts the implement are necessarily modified to suit the nature of the so and the requirements of the agriculturist. The furrow slice is c horizontally from the subjacent land by means of the share Fig. 6, and vertically from the adjacent soil by means of coulter C; and when cut is turned over by the breast or mouldbo M. The coulter is fixed upon the front part of the beam; the sh and breast are carried by the frame, which is fastened to the hin part of the beam. The vertical pressure of the plough upon ground is taken by the sole-plate P, which is fixed to the under of the frame; and the side pressure of the plough upon the lan taken by the side-plate L, which is attached to the side of the fra The frame with its attachments constitutes the "body" of plough, and the character of the implement depends upon this of it.

The share S, Fig. 6, is usually of cast iron, of a triangular fo and is fixed to the frame by means of a socket, and secured by a or hook. The share has not only to cut the underside of the sli but to give the slice a certain twist, and also to commence to tur over. Its upper surface must be a continuation of the sweep of breast, and its under surface is usually hollowed out so as to ren the cutting edge more acute. The ordinary length of the share about 10 inches, and the width somewhat less than the width the slice, so that the slice is not entirely cut from the grou beneath. If the share is of a width sufficient to cut the sl completely, the slice is apt to be pushed aside by the lateral thr of the front part of the breast, and partially broken, instead of be uniformly turned over; but by leaving a narrow strip uncut, a late resistance is provided which prevents this.

For paring turf or stubble a broad steel share about 15 inc wide is used; and for very strong land the share terminates long and narrow point, which finds its way between the stones gradually pushes them aside, thus diminishing the shock w would be caused by a short point meeting a heavy stone.

A slight "pitch" is usually given to the share; that is, the point inclined downwards, in order that the share may have no lency to run out of the land and diminish the depth of the t.

The front part or neck of the frame, on which the socket of the is fitted, is sometimes for economy made solid; but in the improved ploughs the share is fixed to the end of a lever, called ever-neck, which admits of a slight motion about a horizontal so that the pitch of the share may be adjusted.

; is most important that the cutting edge of the share should be sharp, otherwise the draught of the implement will be materially ased. This object is effected by the method of chilling cast-shares, which was introduced by the late Mr. Robert Ransome of ich in the year 1803. The under surface of the share is chilled sting, and thereby rendered extremely hard, whilst the upper ce remains comparatively soft; the effect being that the soft r surface of the share wears back from the hard under surface, h therefore always presents a sharp cutting edge.

he coulter C, Fig. 6, is usually in the form of a heavy knife-, terminating in a rectangular or cylindrical shaft, by means of h it is attached to the beam. The form of the beam and the e of the attachment must be such as to admit of the coulter g set at the particular angle with the vertical which is required e nature of the soil. When the coulter-shaft is cylindrical, the ng edge of the coulter should be as near to, and the back of the as far behind, the axis of the cylindrical part as possible; so the direction of the resultant resistance of the earth on either of the blade may pass behind the axis, and consequently the er may have no tendency to turn round its axis.

he sharpness of the coulter is as important as that of the share, may be secured by similar means. The coulter being of wrought its land side may be laid with steel and hardened; and thus the al wear will, as in the case of the share, preserve a sharp edge.

here the soil is of a peaty or fibrous texture and free from , as in the fen districts, a skeith or disc coulter, consisting of a

thin steel disc with a sharp cutting edge, which can rotate on a transverse horizontal axis, is used in preference to a knife coul

Leaving the cutting parts of the plough, we proceed to cons the breast or mouldboard M, Fig. 6, by means of which the fur slice is turned over: the form of which has been, and still i fruitful subject for discussion. The nature of the work done depe almost entirely upon the shape of the breast, which must be ada to the style of ploughing that is required. In England the prevai style differs from that of most other countries. The usual pra on the continent is to break up the furrow slice as much as pos at the same time turning in the old surface and the weeds as far consistent with this; the result being that the work done is sin in character to that which would result from digging by hand. England, on the other hand, the practice is to cover completely weeds and the old surface, and to expose a fresh surface, but a same time to leave the furrow slice in an unbroken condition may be doubted whether the English style is the best; but discussion of this question belongs rather to the farmer tha the engineer, who must supply the farmer with an implement w will meet his view of the case.

The question as to whether the solid English furrow slice sh be rectangular or trapezoidal has been elaborately discussed; though the trapezoidal form is still adopted in many localities weight of opinion is greatly in favour of the rectangular se In ploughing at a given depth, the draught for a high-crested fu is said to be greater, while the weight of earth turned is with the trapezoidal than with the rectangular section, and practical result upon the crops has been found by careful trials t inferior. The Royal Agricultural Society has laid down a standard of excellence "That the plough should cut the sole o furrow perfectly flat, leave the land side clear and true, and la furrow slices with uniformity, with perpendicular cut of the side."

In considering the rectangular form of furrow slice, the que arises as to the angle at which the slice should be laid (which

termines the proportions of breadth to width in the slice) in order at the result may be most beneficial. Where seed is to be sown oadcast, it is important that the sides of the furrow should be ually inclined, so that the seed may roll to the bottom of the rrow; but for most purposes the equal inclination of the sides of furrow is a matter of little importance.

As all the slices must be laid in parallel positions, it will be seen n Fig. 1, Plate 79, that, when the thickness or depth A B and the ination D A E of the sod are given, the width is at once rmined, and is equal to A K or B F, where B F is a horizontal drawn through B to meet A D. If D G be the vertical distance) from the line A E, then, since B F A and D A G are similar ngles, and the width B F = D A, therefore the depth B A = D G. ce we may note that, whatever the width or inclination of the e may be, the bottoms of the troughs between the ridges are ays on a level with the original surface of the ground; and refore, if seed be sown broadcast, the level to which the seed falls the ploughed land coincides with the original surface.

Suppose that the ground is required to be ploughed to a given th a, and let i be the inclination of the sod to the bottom of the row; then

Width of slice A D $= \dfrac{a}{\sin i}$

Exposed surface of slice per unit of area of field . . . . $\Big\} = \sin i + \cos i$

Height through which centre of gravity of slice is raised . . . . $\Big\} = \frac{1}{2}\, a \cos i$

we proceed on the supposition that the best form of furrow slice that which exposes the greatest amount of surface, we have this osed surface a maximum when $\sin i = \cos i$, that is, when $i = 45°$. is is the angle which is generally regarded as the most antageous.

It may however be argued with justice that the best form of e is that which exposes the land most to the combined ntegrating effects of the air and moisture; and that this result will

be attained when the whole mass of land turned (not merely the contained in the ridges) is most raised above its original posi For since the whole land must settle down to its former level u the action of the harrow and the weather, and since this settlen involves the breaking and crushing of the slice, attended with admission of air into the crevices, it follows that the amoun this settling action should be the greatest that can be produ This result will be attained when the centre of gravity of the e turned over is as high as possible.

The height through which the centre of gravity of the whole moved is raised by the plough being $\frac{1}{2}\ a \cos i$, we see that elevation of the centre of gravity due to ploughing increases as angle at which the slice is laid diminishes, and therefore as proportional width of the slice increases. From this point of therefore it will be advantageous to increase the width of the fu slice, though of course there is a practical limit beyond which cannot be done. For very many purposes however the widt the slice might be twice its depth, in which case the ang inclination of the slice is 30° instead of 45°. The following T gives the comparative results for the angles of 45° and 30°:—

Angle of inclination	45°	30°
Depth of slice	6 in.	6 in.
Width of slice	8½ „	12 „
Surface exposed per sq. foot of field	203 sq. in.	196 sq. in.
Height through which the centre of gravity is raised	2·12 in.	2·60 in.

Hence it appears that by laying the slice at an angle of 30°, in of at an angle of 45°, we have only 3½ per cent. less of new su exposed, whilst the whole mass of soil turned is raised 22½ per higher. This result is of course independent of the depth of ploughing, so long as the proportions of the furrow slice are prese Hence it would seem that whilst one desideratum of ploughin the exposure of new surface—is still attained to almost the s

extent, we attain another desideratum—the pulverisation and disintegration of the earth—to a much greater extent.

A considerable saving in time and labour would result from the adoption of these proportions of furrow slice—namely the width twice the depth—wherever it may be practicable. In ploughing at a depth of 6 inches on a heavy soil we may take the elements of the draught to be roughly divided as follows:—30 per cent. due to the friction resulting from the weight of the implement, 50 per cent. due to the cutting of the slice, and the remaining 20 per cent. due to the turning of it. The widths of furrow slice under consideration—namely $8\frac{1}{2}$ and 12 in.—are in the proportion of 70 to 100. Hence, supposing the implement to travel at the same speed in both cases, 30 per cent. of time will be saved, 9 per cent. of draught by the diminished loss of energy due to friction, and 6 per cent. of draught by the saving in the vertical cut. That is to say, there is a saving of 30 per cent. in time, and 15 per cent. in labour.

Assuming that the furrow slice is to be turned over in as solid and unbroken a state as possible, we have to give to the breast the form which shall do this in the best manner and with the least draught. To leave the furrow in an unbroken state, the action of the breast upon it must be as gradual and uniform as possible, and the length of the breast must therefore be considerable. For "match-ploughing" a breast from 4 to 5 feet in length is used; for ordinary work from 3 to 4 feet is the usual length. Where it is desired, as in Norfolk ploughing, to leave the ground in a more broken state, a breast of about 2 ft. 6 in. in length, and of a cross section concave to the slice, is used. In ploughing wet clay lands the soil adheres to a long breast, and forms a thin layer over it, which seriously increases the draught. A short breast must therefore be used, the effect of which is that the action of the breast being concentrated, as it were, over a less extent of surface, the pressure between the slice and the breast is sufficient to keep the surface clean.

The practice of makers as to the twist of the breast varies considerably; some give a uniform twist, others a twist gradually increasing from the share to a point nearly midway in the length

consider the nature of this surface.

Let A B C D, Fig. 2, Plate 79, repres
section of a furrow slice, G being the cent
During the first period the section is tu
and the centre of gravity rises until the
During the second period the slice still tu
on its side A D_1 in a vertical position, a
meantime falling. During the third peri
point D_1, and the centre of gravity again
becomes vertical. Lastly, during the f
gravity is falling, and the section turns
its final position, and rests upon the slic
be seen that the respective angles through
during each of these periods depend upon t
slice: the first two periods however alway
turning, and the last two the remainder of
be divided longitudinally into four portion
four periods, the length of each part, in t
proportioned to the angle of turn during t

The true form of the breast for the
minimum of draught involves a problem
of any but a very approximate, and practi
determination. The problem is compli
overlooked that the form of the twisted

nclination would bring the section into the position $A B_3 C_3 D_3$, whereas the true position is $A_2 B_2 C_2 D_1$. Hence the form of the ice, from the point where its section is vertical, is obtained y a twist about A, combined with a rectilinear displacement of very intermediate section, sufficient to bring its lower edge D_3 into e line through D_1 at right angles to the plane of the section. If e slice could be treated as an elastic body, a practical approximation the form of surface required would be obtained by laying a slice of ome elastic material on a horizontal plane and twisting it into the equired position, and then finding the projections of the surface so btained and its generating lines: and perhaps the form thus found might be practically useful. The furrow slice is not however an lastic body, and therefore the only reliable final criterion of the xact form for the surface of the breast must be arrived at by numerous experiments with trial forms in the field.

It is found that the best practical form of breast differs but ittle from the fundamental form, namely a surface generated by traight lines and giving the slice a uniform rotation proportional to the distance traversed along the length of the breast. Taking the width of the breast as everywhere the same, and equal to the width of the furrow slice, the surface of our fundamental form of breast will be generated by a straight line of length equal to the width of the furrow slice, moving uniformly at right angles to two parallel horizontal axes at a distance apart equal to the depth of the furrow slice, and at the same time turning uniformly about one or other of these axes. For the first two divisions in the length of the breast the extremity of the generating line passes through the first axis; for the last two divisions of the breast the generating line moves at a constant distance from the second axis equal to the depth of the furrow slice. The projections of this fundamental form of breast on three planes at right angles may be easily obtained. The angle through which the slice is turned being divided into a convenient number of equal small angles, Fig. 3, Plate 79, the length A F which s fixed on for the breast must be divided in a series of points nto the same number of equal parts, and perpendiculars must be rawn from these points to meet lines parallel to A F from

the extremity of the generating line at each angle. A series points on the outlines of the projections is thus found, and curves drawn through these points will give the outlines. We that the surface of the breast for the first two divisions, *i.e.* up the point B_1 where the generating line is vertical, is a true heli or screw surface; whilst the surface for the last two divisions fr B_1 to B_2 is a helicoidal surface of a distinct and separate charac These two surfaces are however quite continuous (using the w in its non-mathematical sense), since they meet in the same verti generating line, though the upper edge of the breast at B_1 not a continuous curve.

Let us now consider the variations which this fundamental f must undergo for practical purposes.

(I.) In the form adopted by the principal makers, the twist of breast gradually diminishes from a line near the vertical generat line A B_1; hence, in setting out our projections, the spaces i which the lengths A F are divided, corresponding to the equal ang into which the twist is divided, must gradually increase towards extremity F of the line.

(II.) In order that there may be no tendency in the breast to p the slice laterally aside in the operation of turning, the bearing the breast on the slice must not be uniform over the whole surf If it were so, the resultant pressure on any section A B C D, Fig would act at the point K through the centre of gravity of section, and would tend to lift the section bodily: thus relieving pressure at the point A, and tending to push the slice aside, and the same time to break and distort it. The resultant pressure of breast must therefore pass through some point L sufficiently beyond to prevent these results; and a distance B L equal to about a fifth A B is found to be the best. Our fundamental form must therefore further modified by taking, throughout the first two divisions of length, a curved generating line convex to the slice, and having greatest convexity at about one-fifth the width of the slice from upper edge. The convexity of the generating line may gradual become less during the third division of the breast, and disappe during the fourth division.

[t is essential to good ploughing that the slice should be me to its place upon the one previously laid; especially seed is to be sown broadcast, and would fall through any between the slices into the hollow beneath. This end tained either by giving the last division of the breast a owards the slice, so as to bring some additional pressure to ; or by prolonging the surface of the breast for an inch or tail end, with the same twist as the preceding surface, e breast shall terminate in a generating line making an the ground slightly more acute than the angle at which s to be laid. The result in either case will be to bring pressure to bear on the slice, and so to press it home.

The projections of the fundamental form are those of a breast qual in width in every part to the furrow slice. There is need that this should be so; indeed, for soil that will hold he breast may take the form of a narrow strip at a distance ne-fifth the width of the slice from the upper edge of the al form, the rest of the breast being entirely cut away. would fall to pieces if turned by such a breast; but may in all cases be diminished to some extent. Hence e of the fundamental form may be cut and trimmed, to aceful and continuous contour, as well as to diminish the the breast.

the fundamental form the front line b A of the breast, uld be the cutting edge, and the slice after passing this receive the whole of its twist. In practice this cutting ther with the front part of the breast, has to be replaced are, of which the front or cutting edge b H must lie in ntal plane through A F, and is therefore out of the surface ast. Hence the form of the surface towards the front ghtly changed, so that it may sweep into the line b H.

are the chief modifications which must be made in the al form of the breast in order to render it best adapted for om the foregoing considerations it will be seen that any form of breast can be perfectly adapted only to one

particular size of furrow slice. The first two divisions surface, that is the front part of the breast up to the generating line A B, may indeed be the same for a cons range of variation in the width and depth of the slice; the divisions however depend on the particular dimensions Hence the suggestion presents itself that for ploughs for purposes, intended to work at any depth from 4 to 9 or 10 the breast might be made in two parts meeting on the generating line, so that the tail part might be varied different depths and widths, or different styles of work. In of this, the question arises as to what is the best form for which is intended to be used at different depths. It h thought that the form adopted should be that which g lightest draught in deep ploughing; but since the draught turning is the smallest element in the total draught, this is the consideration of greatest importance. It is of more im that the work should be effectively done, and especially that should be pressed home to its place. It will be seen from Plate 79, where A B C D, A E F G represent similar different depths, in the vertical position, and $a\,b\,c$ D, represent the final positions of those slices, that, since the D K between D c and G g is less than the difference D G the depths of the slices, the final position $e\,f$ of the surfac shallower slice is lower than the final position $a\,b$ of the slice. Hence if the shallower slice were ploughed with adapted to the deeper work, there would be no pressure on from the tail of the breast, and consequently it would not be home. It would therefore seem better to adapt the ploug a depth of 5 or 6 inches, which would give an extra pressu when ploughing at a greater depth. The extra pressure in practice by means of a set-screw at the tail of the breast varying the adjustment of the tail by this means the whole is necessarily shifted from its true position.

Hitherto we have considered the form of the breast with solely to the work to be performed by it, and without referen draught of the plough. As before stated, the draught du

ast is generally but a small part of the total draught, and hence point is of less importance, especially as the nature of the work e is always the paramount consideration. It is generally found rever that the breast which does the most satisfactory work takes least draught. Experiment has shown that an increase in the gth of the breast decreases the draught to a small extent, as ;ht have been anticipated; whilst the convexity of the breast ards the slice causes a further decrease. The frictional work e is proportional to the product of the friction and the space rersed. The length of the line of maximum pressure, traced on fundamental form at a constant distance from the edge, increases he line is taken further from the axis A F, Fig. 3 ; but the pressure l the consequent friction diminish in a much greater ratio, owing to increase of leverage. Hence it is an advantage in point of ught to have this line of maximum pressure (*i.e.* line of greatest vexity) as near the outer edge of the breast as is practicable. however it be taken too near, the slice would be broken; and ice the distance of one-fifth from the edge is about the best as ards draught. Again, the less the torsion to which the slice is jected, the less the draught; but this exercises only a minute uence on the result. Hence the general conclusion is that the m of the breast is to be determined with reference to the quality the work, rather than to the power required to do it. Our efforts diminish the draught must be chiefly directed to the other parts the implement.

The best material for the breast is steel. Cast iron is perhaps re often used, for the sake of economy, and works well on a dry l; but steel, being more durable and capable of taking a much er polish, is to be preferred, especially for adhesive soils.

The essential parts of the plough which we have still to ntion are the frame, the sole-plate, and the side-plate. The frame isually of cast iron, of a form adapted to the attachment of the erent members of the body; and, in common with all other parts he plough, should be as light as is consistent with strength. The -plate P, Fig. 6, Plate 80, is made of hard cast iron; its bottom

[illegible]

[illegible] ploughs. Some of the most ancient [illegible]
there is any record were furnished with [illegible]
though it was for some time hotly [illegible]
generally recognised. Mr. Sullivan, in
Magazine for 1845, tells us that "It is [illegible]
a backward condition that those re[illegible]
ploughs are now used;" but, despite th[illegible]
neighbours in favour of the swing plo[illegible]
steadily made its way, even in Scotland.
are commonly used: if only one, it run[illegible]
if two, then one runs on the land and th[illegible]

The only proper office of wheels is [illegible]
plough, by lessening the effect of the [illegible]
and to the varying nature of the soil, [illegible]
tendency of the plough to pitch in to [illegible]
more land, in any tougher soil which [illegible]
office of the wheels is often superadded [illegible]
the regulation of the depth of the furrow [illegible]
must be adjustable to the required de[illegible]
furrow should determine the depth of [illegible]
The implement should be so set, by [illegible]
pitch of the share, as to work as a sw[illegible]

All the essential parts of an ordinary plough have now been considered. It remains in the next place to enquire what are the forces which act on the plough when at work; to attempt to analyse the complex elements of the draught, and to consider some of the means by which these elements may be severally lessened. We have then to consider the advantages arising from the use of multiple-furrow ploughs; and finally to notice shortly some other kinds of ploughs, and the remaining implements which were enumerated at the beginning as suitable for cultivating land by horse-power. This part of the subject must however be reserved for another occasion.

Discussion.

Mr. Bousfield asked permission to call attention to several specimens of ploughs, kindly sent by three different makers. Some of the observations made in the paper might seem to describe parts of the plough which were too well known to need description; but they would really be seen to be necessary, in order to connect the various divisions of the subject. On the other hand, many considerable variations in the mode of making ploughs had not been noticed, because he had not looked at the subject so much from the point of view of construction, and had only considered those variations in form which made some practical difference in the doing of the work. Those variations were illustrated by the different forms of plough body now exhibited. The first (Plate 80, Figs. 6 and 7) was

a new form recently brought out by Messrs. Howard, of Bedford, a called the Simplex Plough. The beam of this plough was T shap in section, to secure lateral strength; and was curved downwa towards the share, to receive a pair of cheeks, which embraced leaving a space between the cheeks for receiving a lever neck, the outer end of which the share was fitted. The next (Fig. was a body sent by Messrs. Ransomes Sims and Head, of Ipswi There was a cast or wrought iron body introduced into the mid of the beam, which was forked for the purpose, and thus formed truss, which gave considerable rigidity to the working parts of t plough, especially to the coulter, and enabled the beam to bear gr torsional strain. The third (Figs. 9 and 10) was from Messrs. Horns of Grantham; the frame was here in one piece with the beam, b being forged together. The fourth, also from Messrs. Hornsby, w adapted for match-ploughing; and not, like the third, for Lancash work. He had received a letter from Mr. James Hornsby, which, that gentleman could not attend to take part in the discussion, might be permitted to read; it was as follows:—

"I notice that on page 535 you remark that the lever-ne admits of a slight motion to give pitch to the share. This l been the usual custom in ploughs, but you will find in our 'R plough (Fig. 9) that we also give a lateral movement to the share a principle of our own. On page 545 you say the frame is usua of cast iron. But from the commencement of our making ploug at Warwick we have always used the wrought-iron frame, as sho in the bodies of the 'S' and 'R B' ploughs, thus combining streng with lightness without the use of nuts or bolts. The 'S' plou is fitted with a long breast, for prize work, which produces a so and unbroken furrow, and is set at an angle of 45°. The 'R (Fig. 9) is fitted with breast, coulter, and share, of suitable fo for producing the high cut or Lancashire work, as required in th district."

Mr. Daniel Adamson had been a farmer for thirty years, thou he had farmed more for pleasure than for profit; and he w exceedingly glad to find that the Institution had a paper on

mportant a subject as that before them, a paper which would help to llustrate the economy of the cultivation of land. The improvements nade in any one implement might seem of small importance; but it was a matter of great importance that the engineers of the country were devoting their attention to this subject. Up to 1825, about the ime of the opening of the first railway in the country, there was not a single agricultural implement workshop of any importance in the ingdom. Now they existed by scores, and, as he hoped, were eaching the farmer how to till his land at the least possible cost, whether by the use of animal power or steam power. He hoped that n future papers steam cultivation would also be treated, and that a full exposition would be given of all implements used in connection with agriculture. This was not a light matter when it was remembered that about thirty-three million acres of land were under cultivation n the country; so that an increase in its producing power to the xtent of £3 per acre would represent no less than one hundred nillions sterling. That, he believed, was about the difference etween the value of a good and a bad harvest in the country. He hould have been glad if the author could have given illustrations of he old plough as used by the Romans and our earliest forefathers, nd from thence down to the present time; so that there might be a omplete record of the whole series.*

He thought that the agricultural engineer was entitled to more onsideration than he had at present received at the hands of gricultural societies. Any one who had experience in that direction rould bear him out when he stated that, amongst the prizes given by he Royal Agricultural Society, a very small proportion was given o implement makers. He hoped that in future the Society would ive larger prizes than they had hitherto done, for new implements nade to economise the labour of man and horse. Agricultural ngineers would then take up the matter more eagerly, in order to ecure the prizes, and the interests of England would be advanced by timulating increased production with less cost.

* See on this subject 'Ploughs and Ploughing,' by J. E. Ransome (Constable, dinburgh, 1865).

Mr. Charles Cochrane desired to express his best thanks to Mr. Bousfield for his paper, because for the first time in his life he was enabled to see the principles on which a plough worked. It was a great advantage thus to bring before the Members of the Institution the very first conditions and elements on which successful ploughing depended.

Mr. Jeremiah Head said he felt somewhat diffident in making any remarks on this subject, because it was nearly twenty years since he had had anything to do with ploughing. From 1856 to 1862 he had been associated with the late Mr. Fowler, of Leeds, and had then had a great deal to do with steam ploughing. In fact in those days he had himself ploughed many hundreds of acres by steam power; and also did a considerable quantity of mole ploughing for drainage, to which allusion had been made in the paper. He had often watched the water run out of the drains so made, without the use of any draining tiles whatever. So far as he knew, this system seemed to answer very well, where the nature of the soil and the level of the surface were suitable; and the farmers were well satisfied with it.

He was somewhat struck by the fact that during the past twenty years there did not seem to have been any material alteration made in the forms of ploughs. The essential parts seemed to be the same; and so with almost everything, even down to the fastenings and so forth. Steam ploughing however had altered in character a great deal. One great improvement was the adoption of two self-moving engines, instead of one engine and an anchor. In that way each heavy implement could move itself about from place to place, instead of needing horses to draw it, which was a very great advantage. There was also an improvement by the adoption of steel instead of cast-iron for all the gearing. Formerly the gearing was continually breaking down, by the engine getting in bad gateways or soft ground; but that was very much avoided by the use of steel gearing.

One great desideratum supplied by steam ploughing was that, immediately after the harvest was gathered in, the stubbles could be

d over and ploughed, so as to leave a maximum of time for ure to the weather before the seed time came. In furtherance of bject it was desirable to make the day's work as long as possible ch times. Imbued with this idea he remembered devising a system ughing by lamp-light. A large bull's-eye lantern was put on lough and made to shine exactly in the furrow in front of urrow-wheel, so that the man had nothing to do but watch oint in the furrow, and he could guide the plough accurately. ploughing for some hours in that way, he had found on the ving day that the furrows were just as straight as if they had made in the daylight. Lights on the engines and a hand light e plough served as a ready means of signalling. Mr. Bousfield l be able to inform them whether there was now any steam ghing carried on by night. Considering the importance of g a large amount of work done in the autumn, immediately the harvest, lamp-light ploughing seemed a matter that ought be allowed to drop.

[r. Bousfield said he was not aware of any night ploughing now on; but the electric light had been brought to such perfection, there ought to be no difficulty in ploughing at night, if it was dered desirable.

he President observed that the electric light had been used loughing on several occasions; not only had ploughing been by means of electricity in France, but the electric light had actually used to enable ploughing to go on at night. With nce to Mr. Head's remarks on steam ploughing, he was himself at the Royal Agricultural Show at Leicester in 1868 in nce to steam ploughing, just before the time of two engines employed. At that time there was an engine on one side of eld and an anchor on the other; and a portion of the power e engine that was now lost was then utilised, so that it was considering, in reference to the arrangement of steam ploughs, far that loss could be made up now. A plough that would take t. to pull must have a pull of 5 cwt. on the tail, to keep it

straight and steady. That tail pull if merely made to act as
was altogether lost; but if the tail pulling rope passed r
pulley on an anchor, and so back again to the winding dr
the engine, it made a pull on the opposite side of the dru
therefore a great part of the loss was prevented. But
there were two engines, one on each side of the field, one
let out the rope by means of a brake, while the other was p
and therefore the back pull on the tail rope was entirel
But the advantage of having only a single wire-rope across th
was, he believed, paramount to almost every other conside
The cost of wire ropes per acre for steam ploughing was a
considerable item. It used to be 2s. an acre, but now he beli
was reduced to 10d. or 9d. One reason for that was that the
were now all made of hard-drawn steel wire, i.e. hardened to
blue temper, and then drawn to the proper size. It was
stronger and better and harder than if it had been annealed an
drawn; for in the latter process of drawing, the outside skin
wire was made very hard by bench-hardening, while the insid
soft, and if that wire was torn asunder it gave way unequall
outside separating long before the inside. If, on the contrar
steel was hardened to the same degree as that produced by the b
hardening upon soft wire, the whole wire was equally strong in
part, and it might be drawn down to any size without sof
again. That was the original principle of the Austrian "
Wire," which used to sell for 3s. 6d. a pound, when the process
secret; but now all the best pit ropes, and all the wire rop
steam ploughing, were made of hard-drawn steel wire, which w
course lighter and stronger, as well as harder, so that it resist
grinding action of the earth better, and pressed upon it wit
weight. Such ropes had contributed much to the success of
ploughing.

The question of steam ploughing was altogether one of
interest. Some trials had been made at Leicester which were
extremely interesting character. The ground had there
ploughed to 18 in. deep, and being very hard the pieces of
brought up were as large as paving-stones. Now when the so

thus turned up 18 in. below the surface, it was practically turning up *a new farm* out of the ground, and the gain achieved in that way for the farmer was enormous, as ordinary ploughing never went down half that depth.

He begged to propose a vote of thanks to Mr. Bousfield for his very interesting paper, and hoped he would favour the Institution with further information on a future occasion, so as to bring their knowledge up to date.

The vote of thanks was unanimously agreed to.

The President, in adjourning the meeting, said he might mention that the arrangements for the next summer meeting at Newcastle-on-Tyne were in progress, that some interesting papers were already promised for the occasion, and that there was every prospect of the meeting being a most successful one.

The Meeting then terminated.

INDEX.

1880.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1880.

HONORARY LIFE MEMBERS.

1865. **Downing,** Samuel, LL.D., Trinity College, Dublin; and 4 The Hill, Monkstown, near Dublin.

1873. **Lindsay,** Lord, M.P., F.R.S., 47 Brook Street, Grosvenor Square, London, W.; and Haigh Hall, Wigan.

1867. **Morin,** General Arthur, Director, Conservatoire National des Arts et Métiers, Paris.

1878. **Rayleigh,** Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.

1867. **Tresca,** Henri, Engineer Sub-Director, Conservatoire National des Arts et Métiers, Paris.

MEMBERS.

1878. **Abbott,** Thomas, Northgate Iron Works, Newark.

1861. **Abel,** Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1874. **Abernethy,** James, 4 Delahay Street, Westminster, S.W.

1876. **Adams,** Henry, 60 Queen Victoria Street, London, E.C.

1875. **Adams,** Thomas, Ant and Bee Works, West Gorton, Manchester.

1879. **Adams,** William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1848. **Adams,** William Alexander, Walford Manor, near Shrewsbury.

1859. Adamson, Daniel, Engineering Works, Dukinfield, near Manchester ; The Towers, Didsbury, Manchester.
1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, Manchester.
1878. Adcock, Francis Louis, Post Office, Cape Town, Cape of Good H (or care of William R. Adcock, 17 Rue Neuve de Berry, H France.)
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.
1870. Alexander, Alfred, King William's Town, Cape of Good Hope: (or ca William Alexander, East Cranhams, Cirencester.)
1847. Allan, Alexander, Glen House, The Valley, Scarborough.
1875. Allan, George, Savile Street Engineering Works, Sheffield.
1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.
1870. Alley, John, Engineer and Contractor, Moscow.
1877. Alley, Stephen, Messrs. Alley and MacLellan, 2 Peel Street, London Glasgow.
1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.
1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloom Works, Ilkeston Road, Nottingham.
1876. Allport, Charles James, 11 Queen Victoria Street, London, E.C.
1871. Allport, Howard Aston, Bestwood Coal and Iron Co., Nottingham The Park, Nottingham.
1861. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London,
1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.
1876. Anderson, Henry John Card, 42 Queen Anne's Gate, Westminster, S.
1880. Anderson, James, Vyksounsky Iron Works, Mouram, Russia.
1856. Anderson, Sir John, LL.D., F.R.S.E., Fairleigh, The Mount, St. Leon on-Sea.
1856. Anderson, William, Messrs. Eastons and Anderson, Erith Iron W Erith, London, S.E.; and 3 Whitehall Place, London, S.W.
1878. Angas, William Moore, Imperial College of Engineering, Tokei, Jap (or care of G. D. Angas, Neswick, Driffield.)
1858. Appleby, Charles Edward, Charing Cross Chambers, Duke Str Adelphi, London, W.C.
1867. Appleby, Charles James, Messrs. Appleby Brothers, 89 Cannon Str London, E.C.; and East Greenwich Works, London, S.E.
1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartri Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or car Manuel Cardenosa, 86 Great Tower Street, London, E.C.)
1874. Archer, David, General Manager, Messrs. Brown Marshalls and C Britannia Railway Carriage and Wagon Works, Birmingham.

1859. Armitage, William James, Farnley Iron Works, Leeds.

1879. Armstrong, Alexander, Cargill Street, Dunedin, Otago, New Zealand.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1863. Armstrong, John, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1858. Armstrong, Sir William George, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1873. Arnold, David Nelson, Manager, Midland Wagon Works, Lander Street, Birmingham.

1879. Arrol, Thomas Arthur, Manager, Messrs. P. and W. MacLellan, Clutha Iron Works, Glasgow.

1857. Ashbury, James Lloyd, 66 Grosvenor Street, London, W.

1873. Ashbury, Thomas, Managing Director, Ashbury Railway Carriage and Iron Works, Openshaw, Manchester; and 215 Plymouth Grove, Manchester. (*Life Member.*)

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield.

1875. Atkinson, Edward, Messrs. Richards and Atkinson, Bank Street, Royal Exchange, Manchester; and 4 Richmond Hill, Bowdon, Cheshire. (*Life Member.*)

1869. Austin, William Lawson, Messrs. Austin and Dodson, Cambria Steel and File Works, Arundel Street, Sheffield.

1869. Aveling, Thomas, Messrs. Aveling and Porter, Rochester.

1872. Bagshaw, Walter, Messrs. J. Bagshaw and Sons, Victoria Foundry, Batley.

1865. Bailey, John, Messrs. Courtney Stephens and Bailey, Blackhall Place Iron Works, Dublin.

1860. Bailey, Samuel, Mining Engineer, Perry Pont House, Perry Barr, Birmingham.

1880. Baillie, Robert, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1872. Bailly, Philimond, 62 Rue de la Victoire, Paris.

1880. Bain, William Neish, Messrs. Kyle and Bain, Hong Kong Ice Works, Eastpoint, Hong Kong, China: (or care of George Ogilvie, 110 George Street, Glasgow.)

1873. Baird, George, St. Petersburg; and 5A Cork Street, Burlington Gardens, London, W.

1866. Baker, Samuel, Engine and Boiler Works, 22 Oil Street, Liverpool.
1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.
1879. Baldwin, Thomas, Chief Engineer, Mutual Boiler Insurance Company, Victoria Street, Manchester.
1877. Bale, Manfred Powis, 20 Budge Row, Cannon Street, London, E.C.
1879. Banderali, David, Assistant Locomotive and Carriage Superintendent, Chemin de fer du Nord, Paris.
1870. Barber, Thomas, Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.
1870. Barclay, Arthur, 12 York Street, Covent Garden, London, W.C.
1860. Barker, Paul, Church Road, Yardley, near Birmingham.
1875. Barlow, William Henry, F.R.S., 2 Old Palace Yard, Westminster, S.W.
1866. Barnard, Clement, 4 Billiter Square, London, E.C.
1878. Barr, James, Works Manager, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.
1879. Barratt, Samuel, Engineer and Manager, Corporation Gas Works, Gaythorn Station, Hulme, Manchester.
1862. Barrow, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.
1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury.
1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W.
1860. Batho, William Fothergill, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham; and Belmont, Northfield, Birmingham.
1877. Beale, William Phipson, 6 Stone Buildings, Lincoln's Inn, London, W.C.
1869. Beattie, William George, Junior Athenæum Club, Piccadilly, London, S.W.
1880. Beaumont, William Worby, 163 Strand, London, W.C.
1859. Beck, Edward, Dallam Forge, Warrington; and 21 Bold Street, Warrington. (*Life Member.*)
1873. Beck, William Henry, 139 Cannon Street, London, E.C.
1875. Beckwith, John Henry, Engineer to Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.
1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester.
1858. Bell, Isaac Lowthian, F.R.S., Clarence Iron Works, Middlesbrough; and Rounton Grange, Northallerton; and 16 Eaton Place, London, S.W.
1880. Bell, William Henry, Sir W. G. Armstrong and Co., Central Chambers, Liverpool.
1879. Bellamy, Charles James, 38 Parliament Street, Westminster, S.W.

1857. Bellhouse, Edward Taylor, Eagle Foundry and Iron Works, Hunt Street, Oxford Street, Manchester.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham.

1878. Belsham, Maurice, 6A Victoria Street, Westminster, S.W.

1854. Bennett, Peter Duckworth, Horseley Iron Works, Tipton.

1877. Bennett, Thomas Oldham, Post Office, Melbourne, Victoria.

1872. Bennett, William, Jun., 38 Sir Thomas' Buildings, Liverpool.

1879. Bergeron, Charles, 2 Edinburgh Mansions, Victoria Street, Westminster, S.W.

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1874. Bewick, Thomas John, Mining Engineer, Haydon Bridge, Northumberland.

1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.

1877. Birch, Robert William Peregrine, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1866. Birkbeck, John Addison, 112 Grange Road, Middlesbrough.

1847. Birley, Henry, Haigh Foundry, near Wigan.

1875. Bisset, William Harvey, Board of Trade Surveyor, St. Katharine Dock House, London, E.; and 45 Highbury Quadrant, London, N.

1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1863. Boeddinghaus, Julius, Machine Works and Iron Foundry, Düsseldorf, Germany.

1872. Boistel, Georges, 8 Rue Picot, Avenue du Bois de Boulogne, Paris.

1880. Borodine, Alexander, Engineer-in-Chief, Russian South Western Railways, Kieff, Russia.

1869. Borrie, John, New Exchange Buildings, Middlesbrough.

1862. Bouch, Sir Thomas, 111 George Street, Edinburgh.

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1879. Bovey, Henry Taylor, Professor of Engineering, McGill University, Montreal, Canada.

Tyne

1875. Braconnot, Capt. Carlos, Chief Director and Engineer of the Ma
Arsenal, Correio Geral, Caixa 232, Rio de Janeiro, Brazil; and 10
Vezelay, Paris: (or care of Messrs. Fry Miers and Co., 8 G
Winchester Street, London, E.C.)

1876. Bradley, Frederick Augustus, 39 Queen Victoria Street, London, E.C.

1854. Bragge, William, Shirle Hill, Hamstead Road, Birmingham.

1878. Braithwaite, Charles C., 35 King William Street, London Bridge, Lon
E.C.

1875. Braithwaite, Richard Charles, Manager, Old Park Iron Wo
Wednesbury.

1854. Bramwell, Frederick Joseph, F.R.S., 37 Great George Str
Westminster, S.W.

1868. Breeden, Joseph, Messrs. Breeden and Booth, Cheapside Works,
Cheapside, Birmingham.

1875. Broadbent, Thomas, Chapel Hill Iron Works, Huddersfield.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton.

1879. Brodie, John Shanks, Assistant to Borough and Water Engineer, Munic
Offices, Liverpool.

1852. Brogden, Henry, Hale Lodge, Altrincham, near Manchester. (
Member.)

1877. Bromley, Massey, Locomotive Superintendent, Great Eastern Railw
Stratford, London, E.

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holbo
London, W.C.

1874. Brotherhood, Peter, 56 Compton Street, Goswell Road, London, E.C.; an
25 Ladbroke Gardens, Notting Hill, London, W.

1866. Brown, Andrew Betts, Messrs. Brown Brothers and Co., Rosebank Iro

1869. Browne, Benjamin Chapman, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1874. Browne, Tomyns Reginald, Assistant District Locomotive Superintendent, East Indian Railway, Allahabad, India: (or care of Messrs. B. Smyth and Co., 1 New China Bazaar Street, Calcutta.)

1869. Browne, Walter Raleigh, 10 Victoria Chambers, Victoria Street, Westminster, S.W.

1874. Bruce, George Barclay, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta.

1873. Brunel, Henry Marc, 23 Delahay Street, Westminster, S.W.

1870. Brunlees, James, 5 Victoria Street, Westminster, S.W.

1872. Brunner, Henry, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Cliff House, Appleton, Widnes.

1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.

1873. Buckley, Robert Burton, Executive Engineer, Indian Public Works Department, Seebpore, Calcutta: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1874. Buddicom, William Barber, Penbedw Hall, Mold, Flintshire.

1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester.

1877. Burgess, James Fletcher, Messrs. Ormerod Grierson and Co., 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1874. Burn, William Edward, 171 Portland Road, Newcastle-on-Tyne.

1878. Burnett, Robert Harvey, Locomotive Superintendent, Government Railways, Sydney, New South Wales: (or care of Messrs. Bicknell and Hortin, 161 Edgware Road, London, W.)

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford.

1871. Burrows, James, Douglas Bank, Wigan.

1877. Burton, Clerke, Post Office Chambers, Bute Docks, Cardiff.

1870. Bury, William, 5 New London Street, London, E.C.

1856. Butler, Ambrose Edmund, Kirkstall Forge, near Leeds.

1859. Butler, John, Stanningley Iron Works, near Leeds.

1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.

1877. Campbell, Angus, Superintendent of the Government Foundry and Workshops, Roorkee, India.

1880. Campbell, Daniel, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1864. Campbell, David, 151 Eglinton Street, Glasgow.

1869. Campbell, James, Hunslet Engine Works, Leeds.

1860. Carbutt, Edward Hamer, M.P., St. Ann's, Burley, Leeds; and 23 Wilto Crescent, Belgrave Square, London, S.W.

1878. Cardew, Cornelius Edward, Deputy Locomotive and Carriag Superintendent, Rajputana State Railway, Ajmeer, India: (or car of Messrs. King, King and Co., Bombay.)

1875. Cardozo, Francisco Corrêa de Mesquita, Messrs. Cardozo and Irmão Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs Fry Miers and Co., 8 Great Winchester Street, London, E.C.) *(Life Member.)*

1878. Carlton, Thomas William, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.

1869. Carpmael, Frederick, Highfield, Knockholt, near Sevenoaks.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C.

1877. Carr, Robert, Resident Engineer, London and St. Katharine Docks Co., London Docks, Upper East Smithfield, London, E.

1868. Carrington, Thomas, Mining Engineer, Kiveton Park Collieries, ne Sheffield; and Endcliffe Court, Sheffield.

1874. Carrington, William T. H., 76 Cheapside, London, E.C.

1858. Carson, James Irving, Hillside, Annan, Dumfriesshire.

1876. Carson, William, Engineer, Wallasey Local Board, Egremont, Birk- head.

1877. Carter, Claude, Manager, Messrs. Hetherington and Co., Ancoats Wo Pollard Street, Manchester.

1877. Carter, William, Managing Engineer, Birmingham Patent T Works, Smethwick, near Birmingham; and Imperial Tube Wo Birmingham.

1870. Carver, James, Lace Machine Works, Alfred Street, Nottingham.

1869. Caspersen, Hans William, Engineer, Danish Government Rail Service, 164 Rye Hill, Newcastle-on-Tyne.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Fou 99 Constitution Hill, Birmingham.

1871. Chamberlain, Walter, Fern Bank, Augustus Road, Edgbaston, Birmingh

1866. Chapman, Henry, 113 Victoria Street, Westminster, S.W.; and 10 R Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœni Foundry, Liverpool; and 25 Austinfriars, London, E.C.

1878. Chappé de Leonval, Thomas Fletcher, 29 Stanley Gardens, Kensington Park, London, W.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London E.C.

Chatwin, Thomas, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

Chatwood, Samuel, Lancashire Safe and Look Works, Bolton.

Checkley, Thomas, Mining Engineer, Lichfield Street, Walsall.

Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

Chisholm, John, Messrs. William Muir and Co., Sherborne Street, Manchester; and 30 Devonshire Street, Higher Broughton, Manchester.

Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.

Churchward, George Dundas, Post Office, Launceston, Tasmania; and Kersney Manor, Dover.

Clapham, Robert Calvert, Earsdon, near Newcastle-on-Tyne.

Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan.

Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

Clark, George, Southwick Engine Works, near Sunderland.

Clark, George, Jun., Southwick Engine Works, near Sunderland.

Clark, William, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.

Clarke John, Messrs. Hudswell Clarke and Rodgers, Railway Foundry, Jack Lane, Leeds.

Clarke, William, Messrs. Clarke Chapman and Gurney, Victoria Works, South Shore, Gateshead.

Clay, William, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and 45 North Corridor, The Albany, Liverpool.

Clayton, Charles, Soho Foundry, Preston.

Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

Cleminson, James, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

Clench, Frederick, Messrs. Robey and Co., Perseverance Iron Works, Lincoln.

Closson, Prosper, 48 Rue Laffitte, Paris.

Cochrane, Charles, Woodside Iron Works, near Dudley; and The Grange, Stourbridge.

Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

Cockey, Francis Christopher, Selwood Iron Works, Frome.

Coddington, William, Ordnance Cotton Mill, Blackburn.

Coe, William John, 1 Rumford Place, Liverpool.

1847. Coke, Richard George, Mining Engineer, 39 Holywell Street, Chesterfield, and Brimington Hall, near Chesterfield.

1878. Cole, John William, 54 King William Street, London, E.C.

1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.

1877. Coley, Henry, Manager, Messrs. S. Owens and Co., Whitefriars Street, Fleet Street, London, E.C.

1873. Collingham, Robert Moss, Green Lane Foundry, Queen's Dock Side, Hull.

1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.

1874. Conyers, William, Commissioner of Railways, Middle Island, New Zealand.

1877. Cooper, Arthur, Engineer, Messrs. Brown Bailey and Dixon, Sheffield Steel and Iron Works, Sheffield.

1875. Cooper, Frederick, Chief Engineer, H. M. Gun Carriage Department, Bombay.

1877. Cooper, George, Engineer and General Manager, Buenos Ayres Great Southern Railway, Buenos Ayres: (or care of Secretary, Buenos Ayres Great Southern Railway, 4 Great Winchester Street, London, E.C.)

1874. Cooper, William, Messrs. Gilbert and Cooper, Engineers and Iron Shipbuilders, Neptune Iron Works, Hull.

1878. Cornes, Cornelius, Manager, Messrs. Appleby Brothers, East Greenwich Works, London, S.E.

1848. Corry, Edward, 8 New Broad Street, London, E.C.

1875. Cotton, Francis Michael, Messrs. Field Field and Cotton, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1875. Cottrill, Robert Nivin, Beehive Works, Bolton.

1868. Coulson, William, Mining Engineer, Shamrock House, Durham.

1878. Courtney, Frank Stuart, 3 Whitehall Place, London, S.W.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham; and 9 Rope Walk Street, Nottingham.

1870. Cowen, George Roberts, Messrs. G. R. Cowen and Co., Beck Foundry Brook Street, Nottingham; and 9 Rope Walk Street, Nottingham.

1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.

1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.

1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.

1847. Crampton, Thomas Russell, 4 Victoria Street, Westminster, S.W.

1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.

1878. Crohn, Frederick William, Blackwall Iron Works, Poplar, London, E.

1877. Crompton, Rookes Evelyn Bell, Messrs. T. H. P. Dennis and Co., Anchor Iron Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C.

1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Ditton Lodge, Warrington.

1871. Crossley, William, Furness Iron and Steel Works, Askam, near Dalton-in-Furness, Lancashire.

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester.

1863. Crow, George, Messrs. R. Stephenson and Co., Newcastle-on-Tyne.

1874. Curry, William, Locomotive Superintendent, Great Northern Railway of Ireland, Dublin.

1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester.

1876. Cutler, Samuel, Providence Iron Works, Millwall, London, E.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.

1866. Daniel, Edward Freer, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent; and 11 Needwood Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Oxford House, Horsforth, Leeds.

1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.

1879. Darling, William Littell, Manager of Steel Works, Dowlais Iron Works, Dowlais.

1878. Darwin, Horace, 66 Hills Road, Cambridge. (*Life Member.*)

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich.

1880. Davies, Charles Merson, Locomotive Superintendent, Holkar and Sindia-Neemuch State Railway, Khandwa, India.

1874. Davis, Alfred, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1868. Davis, Henry Wheeler, 11 New Broad Street, London, E.C.

1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester; and 64 Cannon Street, London, E.C.

1877. Davison, John Walter, Messrs. William and John Davison, Engineers and Ironfounders, Moscow, Russia: (or care of Alfred L. Sacré, 60 Queen Victoria Street, London, E.C.)

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.
1874. Davy, Walter Scott, Messrs. Davy Brothers, Park Iron Works, Shef
1874. Daw, Samuel, Pearston House, 23 The Walk, Tredegarville, Cardif
1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1879. Dawson, Bernard, The Laurels, Malvern Link, Malvern.
1876. Dawson, Thomas Joseph, Mining Engineer, Cocken, near Houses.
1869. Day, St. John Vincent, 115 St. Vincent Street, Glasgow.
1874. Deacon, George Frederick, Municipal Offices, Dale Street, Liverpool
1880. Deacon, Richard William, Kalimaas Works, Sourabaya, Java; and Villa, Penarth, near Cardiff.
1868. Dean, William, Locomotive Superintendent, Great Western R Swindon.
1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leices
1877. Dees, James Gibson, 36 King Street, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1872. Denton, John Punshon, Tanton Hall, Stokesley, near Northallerton
1880. De Pape, William Alfred Harry, Tottenham Board of Health, C Croft House, High Road, Tottenham, Middlesex.
1868. Derham, John J., Brookside, near Blackburn.
1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland.
1875. Dickinson, William, Messrs. Eastons and Anderson, 3 Whitehall London, S.W.
1879. Dickson, John, Manager, Mersey Wheel and Axle Works, Stourbric
1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Machine Works, Bolton.
1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, C
1868. Dodman, Alfred, Highgate Foundry, Lynn.
1880. Donald, James, Carnac Iron Works, Bombay.
1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Ya Launch Builders, Church Wharf, Chiswick, London, W.; and House, Turnham Green.
1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Blue Anchor Bermondsey, London, S.E.
1877. Dossor, Arthur Loft, 33 Ladywell Park, Lewisham, Kent, S.E.
1865. Douglas, Charles Prattman, Consett Iron Works, near Blackhill, C Durham; and Consett House, Consett, County Durham.
1879. Douglass, James Nicholas, Engineer to the Trinity Board, Trinity H London, E.C.
1879. Douglass, William, Chief Engineer to the Commissioners of Irish Li Westmoreland Street, Dublin.
1879. Doulton, Bernard, Lambeth Pottery, Lambeth, London, S.E.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Jun., Redbourn Hill Iron and Coal Works, Frodingham, near Brigg.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Post Office Chambers, Middlesbrough.

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C.

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1880. Duckham, Frederick Eliot, Engineer, Millwall Docks, London, E.

1879. Duncan, David John Russell, Messrs. Duncan Brothers, 63 Queen Victoria Street, London, E.C.

1870. Dunlop, James Wilkie, 22 Leadenhall Street, London, E.C.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 9 Delahay Street, Westminster, S.W.

1867. Easton, James, Mining Engineer, Nest House, Gateshead.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1878. Eckart, William Roberts, P. O. Box 1587, San Francisco, California, United States.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1871. Edwards, Edgar James, Butterley Iron Works, Alfreton.

1877. Edwards, Frederick, Superintending Engineer, Weymouth and Channel Islands Steam Packet Co., &c., 127 Leadenhall Street, London, E.C.

1880. Edwards, Robert, 58 London Road, Grantham.

1866. Elce, John, 25 Cathedral Yard, Manchester.

1879. Ellacott, Robert Henry, Messrs. Ellacott and Sons, Plymouth Foundry, Plymouth.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester.

1859. Elliot, Sir George, Bart., Houghton-le-Spring, near Fence Houses.

1869. Elliott, Henry Worton, Metal Sheathing Works, 10 Coleshill Street, Birmingham; and Selly Oak Works, near Birmingham.

1877. Elliot, Thomas Mark, Messrs. Robert Elliott and Sons, Pensher I
Fence Houses.

1880. Ellis, Oswald William, 38 George Street, Edinburgh.

1879. Elsdon, Robert, 76 Manor Road, Upper New Cross, London, S.E.

1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.

1869. Elwell, Thomas, Messrs. Varrall Elwell and Middleton, 1
Trudaine, Paris.

1873. Elwell, Thomas, Jun., Engineer, Messrs. Varrall Elwell and M
1 Avenue Trudaine, Paris.

1878. Elwin, Charles, Metropolitan Board of Works, Spring Gardens,
S.W.

1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingsto
Works, Adderley Street, Birmingham: and Finstal, Bromsgrove

1869. Eyth, Max, Messrs. John Fowler and Co., Steam Plough and Lo
Works, Leeds.

1869. Faija, Henry, 4 Great Queen Street, Westminster, S.W.

1868. Fairbairn, Sir Andrew, M.P., Wellington Foundry, Leeds; and 15
Square, London, W.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine
13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Aven
Gare, St. Ouen, France.

1867. Fardon, Thomas, Messrs. Fardon and Feeny, 40 Queen Street,
E.C.; and 1 Lansdowne Terrace, Stuart Street, Luton.

1876. Fell, John Corry, 23 Rood Lane, Fenchurch Street, London, E.C.

1877. Fenton, James, Manager, Messrs. Kitson and Co., Airedale I
Leeds.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria
London, E.

1870. Ferguson, Henry Tanner, Locomotive Superintendent, Rango
Irrawaddy State Railway, Rangoon, Burmah, India.

1854. Fernie, John, 12 King Henry's Road, London, N.W.

1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.

1872. Fidler, Edward, Platt Lane Colliery, Wigan.

1867. Field, Edward, Messrs. Field Field and Cotton, Chandos Cl
22 Buckingham Street, Adelphi, London, W.C.

1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron
Gloucester.

1865. Filliter, Edward, 16 East Parade, Leeds.

1868. Firth, Arthur, Leeds Iron Works, Leeds.

1874. Firth, William, Burley Wood, Leeds.

1871. Fisher, Benjamin Samuel, Locomotive Superintendent, Somerset and Dorset Railway, Highbridge, near Bridgwater.

1877. Flannery, James Fortescue, 9 Fenchurch Street, London, E.C.

1864. Fleet, Thomas, Crown Boiler and Gasholder Works, Westbromwich.

1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.

1858. Fletcher, Henry Allason, Messrs. Fletcher Jennings and Co., Lowca Engine Works, Whitehaven. (*Life Member.*)

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester.

1872. Flower, James J. A., Messrs. James Flower and Sons, Old Trinity House, 5 Water Lane, Great Tower Street, London, E.C.

1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.

1878. Fontaine, Marc Berrier-, Ingénieur de la Marine, Toulon Dockyard, Toulon, France.

1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1861. Forster, Edward, Messrs. Chance Brothers and Co., Glass Works, Spon Lane, near Birmingham.

1877. Foulis, William, Engineer, Glasgow Corporation Gas Works, 42 Virginia Street, Glasgow.

1866. Fowler, George, Mining Engineer, Basford Hall, near Nottingham.

1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.

1866. Fox, Charles Douglas, 5 Delahay Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1859. Fraser, John, 13 Park Square, Leeds.

1877. Fraser, John Hazell, Messrs. Fraser Brothers, Railway Iron Works, Bromley, London, E.

1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield.

1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1866. Galloway, Charles John, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1862. Galton, Capt. Douglas, C.B., R.E., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.

1880. Galwey, John Wilfrid de Villemont, Messrs. Galwey Whitehead and Co., Warrington Engine and Iron Works, Lythgoe's Lane, Warrington.

[illegible]. [illegible] William Henry, 88 Albert Terrace, Middlesbrough.

[illegible]. [illegible] John [illegible], Executive Engineer, Severn Tunnel Wor[illegible] [illegible], near Bristol.

1881. [illegible] Samuel, Messrs. A. Guinness Son and Co., St. Jame[illegible] Brewery, Dublin.

[illegible]. [illegible] Richard Cadbury, Berkley Street, Birmingham.

[illegible]. Gilbert [illegible] Edwin, Canada Engine Works, Montreal, Canad[illegible]

[illegible]. Gilkes Edgar, Messrs. Hopkins Gilkes and Co., Tees Engine [illegible] Middlesbrough.

[illegible]. Gill Charles, Messrs. Young and Gill, Engineering Works, Jav[illegible] Java Lodge, Beckenham.

[illegible]. [illegible], George, Engineer, [illegible] Hall Colliery, Wigan.

[illegible]. [illegible] Josiah, [illegible] Road Engine Works, Leicester.

[illegible]. Gjers John, Messrs. Gjers Mills and Co., Ayresome Iron [illegible] Middlesbrough.

1882. [illegible], Samuel, Messrs. Bolckow Vaughan and Co., Iron [illegible] Middlesbrough.

[illegible]. [illegible], William Bernard, 54 Regent's Park Road, Regent's [illegible] London, N.W.

[illegible]. Goldsworthy, Robert Bruce, Messrs. Thomas Goldsworthy and [illegible] Britannia Emery Mills, Hulme, Manchester.

18[illegible]. [illegible] William Frederick, Vulcan Foundry, Warrington.

18[illegible]. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, [illegible] near [illegible], Ireland.

18[illegible]. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E[illegible]

18[illegible]. Goodfellow, George Ben, Hyde Iron Works, Hyde, near Manchester[illegible]

18[illegible]. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Swede[illegible]

18[illegible]. Gordon, Robert, Executive Engineer, Public Works Depa[illegible] Henzada, British Burmah, India: (or care of Messrs. Henry S[illegible] and Co., 45 Pall Mall, London, S.W.)

18[illegible]. Gorman, William Augustus, Messrs. Siebe and Gorman, 17 Mason [illegible] Westminster Bridge Road, London, S.E.

1880. Gottschalk, Alexandre, 17 Rue Laffitte, Paris.

1877. Goulty, Wallis Rivers, Albert Chambers, Albert Square, Manchester[illegible]

1871. Gowenlock, Alfred Hargreaves, Messrs. Jessop and Co., E[illegible] Contractors, 93 Clive Street, Calcutta.

1878. Grafton, Alexander, 15 Great George Street, Westminster, S.W.

1869. Grainger, James Nixon, Public Works Department, Chepauk, M[illegible] and The Mall, Newport, Isle of Wight: (or care of G. N. Hen[illegible] Alexandra Terrace, Newport, Isle of Wight.)

1865. Gray, John McFarlane, Chief Examiner of Engineers, Marine Depar[illegible] Board of Trade; 127 Queen's Road, Peckham, London, S.E.

1876. **Gray**, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1870. **Gray**, Matthew, 106 Cannon Street, London, E.C.; and Silvertown Telegraph Works, North Woolwich, E.

1879. **Gray**, Thomas Lowe, Assistant Manager, Ant and Bee Works, West Gorton, Manchester.

1879. **Greathead**, James Henry, 8 Victoria Chambers, Victoria Street, Westminster, S.W.

1861. **Green**, Edward, Messrs. E. Green and Son, Phœnix Works, Wakefield.

1871. **Greener**, John Henry, 14 St. Swithin's Lane, London, E.C.

1878. **Greenwood**, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. **Greenwood**, William Henry, 34 Halston Street, Moss Side, Manchester.

1865. **Greig**, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1880. **Gresham**, James, Messrs. Gresham and Craven, Craven Iron Works, Manchester.

1874. **Grew**, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1866. **Grice**, Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1860. **Grice**, Frederic Groom, Oakley Villa, Westbromwich.

1868. **Grierson**, Henry Houldsworth, Messrs. Ormerod Grierson and Co., St. George's Iron Works, Hulme, Manchester.

1873. **Griffiths**, John Alfred, Cleveland Road, Cheetham Hill, Manchester.

1879. **Grose**, Arthur, Manager, Vulcan Iron Works, Guildhall Road, Northampton.

1870. **Guilford**, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham.

1870. **Gwynne**, James Eglinton Anderson, Essex Street Works, Strand, London, W.C. (*Life Member.*)

1870. **Gwynne**, John, Hammersmith Iron Works, Hammersmith, London, W.

1863. **Hackney**, William, 1 Somerset Place, Mumbles, Swansea.

1879. **Hadfield**, Robert, Hadfield Steel Foundry Co., Attercliffe, Sheffield.

1861. **Haggie**, Peter, Hemp and Wire Rope Works, Gateshead.

1879. **Hall**, John Francis, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1874. **Hall**, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1871. **Hall**, William Silver, Messrs. Hall and Clarke, Canal Street Iron Works, Derby; and 7 Yeovil Terrace, Hartington Street, Derby.

1880. **Hallett**, John Harry, 120 Powell's Place, Cardiff.

1871. Halpin, Druitt, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1870. Hamand, Arthur Samuel, 9 Bridge Street, Westminster, S.W.
1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Campinas, São Paulo, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.
1879. Handyside, James Baird, Messrs. Thomson Sterne and Co., Crown Iron Works, Glasgow.
1870. Hannah, Joseph Edward, Abbeystead, Wyresdale, near Lancaster.
1874. Harding, William Bishop, IX. Bez., Uellöerstrasse Nr. 35, Budapest, Hungary.
1869. Hartfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.
1873. Harman, Harry Jones, Chief Engineer, English and Scottish Boiler Insurance Company, 100 King Street, Manchester.
1879. Harris, Henry Graham, 37 Great George Street, Westminster, S.W.
1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.
1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 9 Alexandra Villas, Hornsey Park, London, N.
1879. Harrison, George, Messrs. Fowler and McCollin, Vulcan Iron Works, Hull.
1871. Harrison, Joseph Edward, Woodside Iron Works, near Dudley.
1858. Harrison, Thomas Elliot, Ealing, Middlesex, W.
1865. Harrison, William Arthur, Messrs. Allen Harrison and Co., Cambridge Street Works, Manchester.
1874. Hart, James, Messrs. David Hart and Co., North London Iron Works Wenlock Road, City Road, London, N.
1877. Hart, James, Borough Engineer and Surveyor, Town Hall, St. Helen's.
1872. Hartnell, Wilson, Park Row, Leeds.
1878. Harwood, Robert, Soho Iron Works, Bolton.
1858. Haswell, John A., North Eastern Railway, Locomotive Department Gateshead.
1857. Haughton, S. Wilfred, Greenbank, Carlow, Ireland. (*Life Member.*)
1878. Haughton, Thomas, 122 Cannon Street, London, E.C.
1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.
1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.
1856. Hawksley, Thomas, F.R.S., 30 Great George Street, Westminster, S.W.
1880. Hawthorn, Thomas, Messrs. Black Hawthorn and Co., Gateshead.
1873. Hay, James A. C., Superintendent of Machinery to the War Department Royal Arsenal, Woolwich.
1879. Hayes, John, 27 Leadenhall Street, London, E.C.
1862. Haynes, Thomas John, Calpe Foundry and Forge, North Front, Gibraltar.

1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.

1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough.

1860. Head, John, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.

1873. Headly, Lawrance, 1 Camden Place, Cambridge.

1857. Healey, Edward Charles, 163 Strand, London, W.C.

1872. Heap, William, 9 Rumford Place, Liverpool.

1878. Heap, William Edward, Assistant Engineer and Surveyor to the Rochdale Corporation, Town Hall, Rochdale.

1864. Heathfield, Richard, Lion Galvanising Works, Wiggin Street, Icknield Port Road, Birmingham.

1878. Hedges, Killingworth William, 25 Queen Anne's Gate, Westminster, S.W.

1875. Heenan, Richard Hammersley, Executive Engineer, Public Works Department, Bhawulpoor, viâ Mooltan, Punjaub, India; and Parsonstown, Ireland.

1879. Henchman, Humphrey, Cape Government Railways, Uitenhage, Cape of Good Hope: (or care of John Henchman, Derby Road, Woodford, Essex, E.)

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China; and Gattaway, Abernethy, Newburgh, Fife.

1878. Henesey, Richard, Superintending Engineer, Messrs. W. Nicol and Co., Byculla Iron Works, Bombay.

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool.

1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.

1877. Hepworth, Thomas Howard, Curzon House, Curzon Street, Derby.

1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.

1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.

1865. Hewett, Edward Edwards, High Court, High Street, Sheffield.

1872. Hewlett, Alfred, Wigan Coal and Iron Works, Kirkless Hall, Wigan.

1872. Hewlett, William Henry, Wigan Coal and Iron Works, Kirkless Hall, Wigan.

1871. Hick, John, M.P., Mytton Hall, Whalley, near Blackburn.

1864. Hide, Thomas C., Messrs. Hide and Thompson, 4 Cullum Street, Fenchurch Street, London, E.C.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1870. Higson, John, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1873. Hildebrandt, John Albert Reinhold, Barlow's Court, 43 Market Street, Manchester.

1871. Hill, Alfred C., Clay Lane Iron Works, South Bank, Yorkshire.

Canterbury Road, Kilburn, London, N.W.

1852. Holcroft, James, Norton, near Stourbridge.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1865. Holliday, John, Messrs. John Bethell and Co., Creosote Wo
Westbromwich; and Oakfield Lodge, Booth Street, Handswo
Birmingham.

1863. Holt, Francis, Midland Railway, Locomotive Department, Derby.

1873. Holt, Henry Percy, 15 Park Row, Leeds.

1867. Holt, William Lyster, 1 Pelham Place, South Kensington, London, S.

1867. Homer, Charles James, Mining Engineer, Stoke-upon-Trent.

1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, Lond
W.C.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbast
Birmingham.

1856. Hopkinson, John, Messrs. Wren and Hopkinson, London Road Iron Wor
Manchester.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., Lighthouse Department, Mess
Chance Brothers and Co., Spon Lane, near Birmingham; and
Westminster Chambers, Victoria Street, Westminster, S.W.

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Work
Huddersfield.

1867. Hopper, William, Machine Works, Moscow: (or care of Thomas Hopp
46 Queen Street, Edinburgh.)

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate
Works, Grantham.

1880. Hornsby, William, Messrs. Richard Hornsby and Sons, Spittlegate
Works, Grantham.

1875. Hosgood, Thomas Hopkin, Gadlys Tin Works, Aberdare; and Troedyrhiew, Merthyr Tydvil.

1873. Hoskin, Richard, 1 East Parade, Sheffield.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, M.P., Messrs. J. and F. Howard, Britannia Iron Works, Bedford.

1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield.

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield.

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W.

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1873. Hughes, Henry, Falcon Iron Works, Loughborough.

1871. Hughes, Joseph, Messrs. Fletcher Jennings and Co., Lowca Engine Works, Whitehaven.

1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.

1880. Humphrys, James, Barrow Shipbuilding Works, Barrow-in-Furness.

1866. Humphrys, Robert Harry, Deptford Pier, London, S.E.

1859. Hunt, James P., Corngreaves Iron Works, near Birmingham.

1856. Hunt, Thomas, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1874. Hunt, William, Jun., Messrs. William Hunt and Sons, Alkali Works, Lea Brook, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E.

1864. Hutchinson, Edward, Streonshalh House, Darlington.

1865. Hyde, Major-General Henry, R.E., India Office, Westminster, S.W. (*Life Member.*)

877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

867. Inglis, William, Soho Iron Works, Bolton; and Astley Bridge, near Bolton.

872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and 45 North Corridor, The Albany, Liverpool.

1872. Jack, Alexander, Messrs. James Jack and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1876. Jackson, Henry James, Superintending Engineer, General Steam Navigation Co.'s Works, Deptford, London, S.E.

1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Budapest, Hungary.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Grosmont, near Hereford.

1873. Jackson, Samuel, Locomotive and Carriage Superintendent, Great Indian Peninsula Railway, Bombay.

1872. Jackson, William Francis, Bowling Iron Works, near Bradford.

1873. Jacob, Edward Westley, care of Henry Jacob, The Woodlands, Habberley Road, Bewdley.

1876. Jacobs, Charles Mattathias, Post Office Chambers, Bute Docks, Cardiff.

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.

1877. James, John William Henry, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1879. Jameson, George, Glencormac, Bray, Ireland.

1870. Jamieson, John Lennox Kincaid, 9 Crown Terrace, Dowanhill, Glasgow.

1876. Jebb, George Robert, Engineer to the Birmingham Canal Navigation, Birmingham; and The Laurels, Shrewsbury.

1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.

1880. Jefferies, John Robert, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.

1863. Jeffreys, Edward A., Monk Bridge Iron Works, Leeds; and Gipton Lodge, Leeds.

1876. Jemson, James, Engineer to the Kay Shuttleworth Mineral Estate, Gawthorpe Hall, near Burnley.

1875. Jenkin, H. C. Fleeming, F.R.S., Professor of Engineering, University of Edinburgh; 3 Great Stuart Street, Edinburgh.

1878. Jensen, Peter, Messrs. Brewer and Jensen, 33 Chancery Lane, London, W.C.

1878. Jessop, Joseph, London Steam Crane and Engine Works, Leicester.

1854. Jobson, John, Derwent Foundry, Derby.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 34 King Street, Chester.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne.

Jones, Charles, Messrs. John Jones and Sons, Marine Engine Works, William Street, Liverpool.

Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

Jones, Edward, Anglo-American Electric Light Co., Victoria Works, Vine Street, York Road, Lambeth, London, S.E.

Jones, Edward Trygarn, Consulting Engineer to the Commercial Steam Ship Co., 32 Great St. Helen's, London, E.C.

Jones, Frederick Robert, Superintendent of Nahan Iron Works, Nahan, Sirmoor State, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

Jones, George Edward, Adamwahan, Punjaub, India: (or care of Mrs. Edward Jones, Woodville, Wylde Green, near Birmingham.)

Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

Jones, William Richard Sumption, Rajputana State Railway, Ajmeer, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

Joy, David, Barrow Shipbuilding Co., 112 Fenchurch Street, London, E.C.

Jüngermann, Carl, Märkisch Schlesische Maschinenbau und Hütten Actien Gesellschaft, 3 Chaussée Strasse, Berlin.

Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.

Kellett, John, 27 King Street, Wigan.

Kelson, Frederick Colthurst, Greenbank, Waterloo, near Liverpool.

Keenan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.

Kennedy, Alexander Blackie William, Professor of Engineering, University College, Gower Street, London, W.C.

Kennedy, James, Cressington Park, Aigburth, Liverpool.

Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

Kennedy, Thomas Stuart, Wellington Foundry, Leeds.

Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Maple Bank, Church Road, Edgbaston, Birmingham.

Kershaw, John, 1 Arlington Street, Piccadilly, London, S.W.

Kessler, Emil, Maschinenfabrik, Esslingen, Wurtemburg, Germany.

King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

Kirk, Alexander Carnegie, Messrs. Robert Napier and Sons, Lancefield House, Glasgow; and Govan Park, Govan, Glasgow.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Workington.
1875. Kirkwood, James, Chief Engineer, Revenue Steamer "Fei-Hu," Kong, China: (or care of Frederick Degenaer, Zetland Stree Kong, China); and Broad Street, Denny.
1864. Kirtley, William, Locomotive Superintendent, London Chatha Dover Railway, Longhedge Works, Wandsworth Road, London,
1859. Kitson, James, Jun., Monk Bridge Iron Works, Leeds.
1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.
1874. Klein, Thorvald, Cliff Vale Wagon Works, Stoke-upon-Trent.
1875. Knight, John Henry, Weybourne House, Farnham.
1877. Kortright, Lawrence Moore, Superintendent of Public Works, St West Indies; and care of G. D. Kortright, Plas Teg, near Mold, Fli

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Birkenhead.
1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Birkenhead.
1873. Lamb, William James, Newtown and Meadows Collieries, near Wig
1878. Lambourn, Thomas William, Messrs. Ransomes and Rapier, Wa Iron Works, Ipswich.
1863. Lancaster, John, Bilton Grange, Rugby.
1877. Lange, Hermann Ludwig, Manager, Messrs. Beyer Peacock an Gorton Foundry, Manchester.
1879. Langley, Alfred Andrew, Engineer in Chief, Great Eastern R Liverpool Street, London, E.C.
1879. Lapage, Richard Herbert, Locomotive Superintendent, Campana R Buenos Ayres: (or care of Clement Lapage, Nantwich).
1879. Larsen, Jorgen Daniel, 7 Poultry, London, E.C.; and Rue Ma Paris.
1867. Lawrence, Henry, The Grange Iron Works, Durham.
1874. Laws, William George, Clarence Iron Works, Leeds.
1870. Layborn, Daniel, Government Engineer Surveyor, Rangoon, B India: (or care of Ellery Turner, Norwood, Beverley.)
1856. Laybourne, Richard, Isca Foundry, Newport, Monmouthshire.
1860. Lea, Henry, 38 Bennett's Hill, Birmingham.
1865. Ledger, Joseph, Keswick.
1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.
1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Tipton; and 110 Cannon Street, London, E.C.
1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Ashton-under-Lyne.

1858. **Leslie**, Andrew, Iron Shipbuilding Yard, Hebburn Quay, Gateshead.

1878. **Lewis**, Gilbert, Manager, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1872. **Lewis**, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

1860. **Lewis**, Thomas William, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1880. **Lightfoot**, Thomas Bell, Messrs. J. and E. Hall, Iron Works, Dartford; and 2 Granville Park, Blackheath, London, S.E.

1856. **Linn**, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1872. **Linsley**, Samuel W., 13 Victoria Terrace, South Shields.

1876. **Lishman**, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1866. **Little**, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. **Livesey**, James, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1867. **Lloyd**, Charles, 167 Howard Place, Shelton, Stoke-upon-Trent.

1871. **Lloyd**, Francis Henry, Darlaston Steel and Iron Works, near Wednesbury; and Wood Green, Wednesbury.

1854. **Lloyd**, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)

1862. **Lloyd**, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire; and Priors Lee Hall, near Shifnal.

1864. **Lloyd**, Sampson Zachary, Areley Hall, Stourport.

1852. **Lloyd**, Samuel, The Farm, Sparkbrook, Birmingham.

1863. **Loam**, Matthew Hill, Gas and Water Engineer, Ivy House, Colwich Road, Nottingham.

1879. **Lockhart**, William Stronach, 4 Finsbury Circus, London, E.C.

1874. **Logan**, William, Mining Engineer, Langley Park Colliery, Durham.

1880. **Longridge**, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. **Longridge**, Robert Bewick, Managing Director, Engine and Boiler Insurance Company, 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. **Longridge**, Robert Charles, Kilrie, Knutsford.

1880. **Longworth**, Daniel, Messrs. Western and Co., Belvedere Road, Lambeth, London, S.E.

1861. **Low**, George, Bishop's Hill Cottage, Ipswich.

1873. **Lowe**, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C.

1873. **Lucas**, Arthur, 23 Delahay Street, Westminster, S.W.

1877. **Lupton**, Arnold, Crossgates, near Leeds.

1878. Lüthy, Robert, Manager, Soho Iron Works, Bolton.

1854. Lynde, James Gascoigne, 32 St. Ann's Street, Manchester.

1878. Lynde, James Henry, 32 St. Ann's Street, Manchester.

1868. Lyndon, George Frederick, Minerva Works, Fazeley Street, Birmingham.

1877. MacColl, Hector, Messrs. James Jack and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1879. Macdonald, Augustus VanZundt, Manager, Auckland Section, New Zealand Railways, Auckland, New Zealand.

1864. Macfarlane, Walter, Saracen Foundry, Possilpark, Glasgow.

1875. Maclagan, Robert, Chief Engineer, Imperial Mint, Osaka, Japan: (or care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.)

1877. MacLellan, John A., Messrs. Alley and MacLellan, 2 Peel Street, London Road, Glasgow.

1864. Macnab, Archibald Francis, Japanese Government Service, Yokohama, Japan; and 2 Cyprus Villas, Sutton Grove, Sutton, Surrey.

1865. MacNay, William, Shildon Engine Works, Darlington.

1865. Macnee, Daniel, 2 Westminster Chambers, Victoria Street, Westminster, S.W.; and Rotherham.

1878. Madge, Henry James, Engineer Inspector of Steam Boilers, 19 Lall-Bazar Street, Calcutta.

1879. Maginnis, James Porter, 10 Victoria Chambers, Victoria Street, Westminster, S.W.

1873. Mair, John George, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1879. Malcolm, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.

1876. Manlove, William Melland, Messrs. S. Manlove and Sons, Holy Moor Sewing-Cotton Spinning Mills, near Chesterfield.

1862. Mansell, Richard Christopher, Mechanical Engineer, South Eastern Railway, Ashford.

1875. Mansergh, James, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1862. Mappin, Frederick Thorpe, M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1857. March, George, Messrs. Maclea and March, Union Foundry, Dewsbury Road, Leeds.

1878. Marié, George, Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, Bureaux du Matériel, Boulevart Mazas, Paris.

1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield; and Tapton House, Chesterfield.

1871. Marsh, Henry William, Winterbourne, near Bristol.

Marshall, Alfred, Perseverance Iron Works, Heneage Street, Whitechapel, London, E.; and Laurel Bank, Prospect Hill, Walthamstow, Essex. (*Life Member.*)

Marshall, Francis Carr, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

Marshall, William Bayley, General Manager, Staffordshire Wheel and Axle Works, Birmingham; and 14 Augustus Road, Birmingham.

Marshall, William Ebenezer, 1 Crossbeck Terrace, Ilkley, near Leeds.

Marshall, William Prime, 14 Augustus Road, Birmingham.

Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge.

Marten, Henry John, Parkfield House, near Wolverhampton; and 4 Storey's Gate, Westminster, S.W.

Martin, Henry, Hanwell, Middlesex, W.

Martin, Robert Frewen, Mount Sorrel Granite Co., Loughborough.

Martineau, Francis Edgar, Globe Works, 278 New Town Row, Birmingham.

Massicks, Thomas, Millom Iron Works, Millom, Cumberland.

Mather, John, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.

Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester.

Matthews, James, 2 Lion Chambers, Broad Street, Bristol.

Matthews, Thomas William, 6 Church Road, Heaton Norris, Stockport.

Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

Maudslay, Henry, Westminster Palace Hotel, Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.) (*Life Member.*)

Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.

Maw, William Henry, 35 Bedford Street, Strand, London, W.C.

May, Robert Charles, 6 Great George Street, Westminster, S.W.

Maylor, John, Churton Lodge, Churton, near Chester.

Maylor, William, Ravenstone House, Farquhar Road, Upper Norwood, London, S.E.: (or care of Messrs. Stanes Watson and Co., 4 Cullum Street, Fenchurch Street, London, E.C.)

McClean, Frank, 23 Great George Street, Westminster, S.W.

McConnochie, John, Engineer to the Bute Harbour Trust, New Works, Bute Docks, Cardiff.

1878. McDonald, John Alexander, 4 Chapel Street, Cripplegate, London,

1865. McDonnell, Alexander, Locomotive Superintendent, Great Southe
Western Railway, Dublin.

1868. McKay, Benjamin, 191 Moss Lane East, Manchester.

1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle
Works, Paisley.

1879. McLean, William Leckie Ewing, Lancefield Forge Co., Glasgow.

1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire R
Manchester.

1858. Meik, Thomas, 6 York Place, Edinburgh.

1857. Menelaus, William, Dowlais Iron Works, Dowlais.

1878. Menier, Henri, 37 Rue Ste. Croix de la Bretonnerie, Paris.

1876. Menzies, William, Messrs. Menzies and Blagburn, Exchange Bui
King Street, Newcastle-on-Tyne.

1877. Merryweather, Henry, Messrs. Merryweather and Sons, Steam Fire-
Works, York Street, York Road, Lambeth, London, S.E.

1875. Merryweather, James Compton, Messrs. Merryweather and Sons
Engine Works, 63 Long Acre, London, W.C.

1877. Michele, Vitale Domenico de, 5 Westminster Chambers, Victoria
Westminster, S.W.

1862. Miers, Francis C., Messrs. Fry Miers and Co., 8 Great Win
Street, London, E.C.; and Eden Cottage, West Wickham
Beckenham.

1864. Miers, John William, 74 Addison Road, Kensington, London, W.

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1856. Mitchell, Charles, Iron Shipbuilding Yard, Low Walker, Newca
Tyne.

1870. Moberly, Charles Henry, Messrs. Eastons and Anderson, Erit
Works, Erith, London, S.E.

1879. Moffat, Thomas, Mining Engineer, Montreal Iron Ore Mines, Whitel

1879. Molesworth, Guilford Lindsay, Consulting Engineer to the Gove
of India for State Railways, Supreme Government, India.

1872. Moon, Richard, Jun., Penyvoel, Llanymynech, Montgomeryshire.

1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Hou

1876. Moore, Joseph, Risdon Iron and Locomotive Works, San Fra
California: (or care of Ralph Moore, Government Inspector of
Rutherglen, Glasgow.)

1872. Moorsom, Warren Maude, Lorne Villas, Clevedon.

1880. Moreland, Richard, Jun., Messrs. Richard Moreland and Son, 3 Old
St. Luke's, London, E.C.

1867. Morgans, Thomas, The Guildhall, Bristol.

1874. Morris, Edmund Legh, New River Office, Clerkenwell, London, E.C

1880. **Morris**, Edward Russell, Messrs. Charles Powis, Carter, and Morris, Cyclops Works, Millwall Pier, London, E.; and Oakhill House, Hampstead, London, N.W.

1868. **Morris**, William, Waldridge Colliery, Chester-le-Street.

1865. **Mosse**, James Robert, General Director of Ceylon Railways, Dimbula, Ceylon.

1858. **Mountain**, Charles George, Eagle Foundry, Broad Street, Birmingham.

1873. **Muir**, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1873. **Muir**, Edwin, 26 King Street, Manchester.

1863. **Muir**, William, 16 Clyde Terrace, Brockley Road, New Cross, London, S.E.

1876. **Muirhead**, Richard, Messrs. Drake and Muirhead, Maidstone.

1865. **Murdock**, William Mallabey, Sun Foundry, Dewsbury Road, Leeds.

1863. **Musgrave**, John, Globe Iron Works, Bolton.

1870. **Napier**, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1848. **Napier**, John, 23 Portman Square, London, W.

1861. **Naylor**, John William, Wellington Foundry, Leeds.

1863. **Neilson**, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow; and Queen's Hill, Ringford, Kirkcudbrightshire.

1869. **Nelson**, James, Marine and Stationary Engine Works, Gateshead.

1860. **Nettlefold**, Joseph Henry, Screw Works, Broad Street, Birmingham.

1879. **Neville**, Robert, Butleigh Court, Glastonbury.

1879. **Newall**, Robert Stirling, F.R.S., Wire Rope Works, Gateshead; and Ferndene, Gateshead.

1866. **Newdigate**, Albert Lewis, 25 Craven Street, Charing Cross, London, W.C. (*Life Member.*)

1877. **Nicolson**, Donald, New Zealand Chambers, 34 Leadenhall Street, London, E.C.

1866. **Norfolk**, Richard, Beverley.

1868. **Norris**, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1869. **North**, Frederic William, Mining Engineer, Rowley Hall Colliery, Rowley Regis, near Dudley.

1878. **Northcott**, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 125 Queen's Road, Peckham, London, S.E.

1868. **O'Connor**, Charles, Mersey Steel and Iron Works, Caryl Street, Liverpool.

1875. **Okes**, John Charles Raymond, 39 Queen Victoria Street, London, E.C.

1880. Oldham, Robert Augustus, 6 Westminster Chambers, Victoria S
Westminster, S.W.; and Whitehall Club, Parliament S
Westminster, S.W.

1866. Oliver, William, Victoria and Broad Oaks Iron Works, Chesterfield.

1867. Olrick, Lewis, 27 Leadenhall Street, London, E.C.

1880. Ormiston, Thomas, Consulting Engineer to the Bombay Port T
Ormidale, Thurlow Park Road, West Dulwich, London, S.E.

1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield.

1867. Oughterson, George Blake, care of Peter Brotherhood, 56 Compton St
Goswell Road, London, E.C.

1847. Owen, William, Wheathill Foundry, Rotherham; and Clifton H
Rotherham.

1868. Paget, Arthur, Machine Works, Loughborough.

1877. Panton, William Henry, General Manager, Stockton Forge, Stockto
Tees.

1877. Park, John Carter, Locomotive Engineer, North London Railway,
London, E.

1871. Parke, Frederick, Bowling Iron Co.'s Works, Withnell, Chorley.

1872. Parker, Thomas, Carriage Superintendent, Manchester Sheffield
Lincolnshire Railway, Gorton, near Manchester.

1879. Parker, William, Chief Engineer Surveyor, Lloyd's Register, 2 White
Court, Cornhill, London, E.C.

1871. Parkes, Pershouse, Tipton Chain Works, Castle Street, Tipton.

1878. Parsons, The Hon. Richard Clere, Airedale Foundry, Leeds.

1877. Paton, John McClure Caldwell, Sourabaya, Java: (or care of Messrs. Ma
Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.)

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard
Works, Colchester.

1880. Peache, James Courthope, Locomotive Works, London and North Wes
Railway, Crewe.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Found
Manchester.

1869. Peacock, Ralph, Aire and Calder Foundry, Goole.

1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Found
Manchester; and Gorton Hall, Gorton, near Manchester.

1874. Peaker, George, Engineer to the Small Arms Ammunition Facto
Kirkee, India.

1879. Pearce, George Cope, 2 St. Helen's Crescent, Swansea.

1878. Pearce, Richard, Deputy Carriage and Wagon Superintendent, E
Indian Railway, Howrah, Bengal, India: (or care of W. J. Tit
57 Lincoln's Inn Fields, London, W.C.)

1867. **Pearce**, Robert Webb, Carriage Superintendent, East Indian Railway, Howrah, Bengal, India.

1873. **Penn**, John, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1873. **Penn**, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1874. **Percy**, Cornelius McLeod, Wigan Coal and Iron Works, Kirkless Hall, Wigan.

1861. **Perkins**, Loftus, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.

1879. **Perkins**, Stanhope, Assistant Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, Manchester.

1863. **Perry**, Thomas J., Highfields Engine Works, Bilston.

1865. **Perry**, William, Claremont Place, Wednesbury.

1878. **Phillips**, John, Manager, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 84 Blackfriars Road, London, S.E.

1876. **Piercy**, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham.

1877. **Pigot**, Thomas Francis, Professor of Engineering, Royal College of Science for Ireland, Dublin.

1876. **Pinel**, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne, Rouen, France.

1879. **Pitt**, Robert, Messrs. Stothert and Pitt, Newark Foundry, Bath.

1878. **Pitts**, George Albert, care of Messrs. J. and W. Pitts, St. John's, Newfoundland.

1871. **Platt**, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1867. **Platt**, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. **Platts**, John Joseph, Avonside Engine Works, Bristol; and 8 Albion Villas, Sydenham Park, London, S.E.

1869. **Player**, John, Clydach Foundry, near Swansea.

1876. **Pollock**, Julius Frederick Moore, Messrs. Pollock and Pollock, Longclose Works, Newtown, Leeds.

1876. **Pooley**, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool.

1869. **Potter**, William Aubone, Mining Engineer, Cramlington House, Cramlington, Northumberland.

1864. **Potts**, Benjamin Langford Foster, 174 Camberwell Grove, London, S.E.

1851. **Potts**, John Thorpe, Messrs. Richmond and Potts, 119 South Fourth Street, Philadelphia, Pennsylvania, United States.

1878. **Powell**, Henry Coke, Messrs. Bartrum Powell and Co., 35 Queen Victoria Street, London, E.C.

1870. Powell, Thomas (Son), Messrs. Thomas and T. Powell, 23 Rue St
Rouen, France.

1874. Powell, Thomas (Nephew), Messrs. Thomas and T. Powell, 23
Julien, Rouen, France.

1867. Powell, William, Carleton, Pontefract.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Ca

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron
Carlisle.

1856. Preston, Francis, Turnbridge Iron Works and Forge, Huddersfie
Netherfield House, Kirkburton, near Huddersfield.

1877. Price, Henry Sherley, Albert Chambers, Albert Square, Mancheste

1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding a
Works, Jarrow; and Rose Villa, Gateshead Road, Jarrow.

1875. Prior, Johannes Andreas, 33 Bredgade, Copenhagen.

1874. Prosser, William Henry, Messrs. Harfield and Co., Mansion
Buildings, Queen Victoria Street, London, E.C.

1875. Provis, George Stanton, Whitehall Club, Parliament Street, Westm
S.W.

1866. Putnam, William, Darlington Forge, Darlington.

1878. Quillacq, Augustus de, Société anonyme de Constructions méc
d'Anzin, Anzin (Nord), France.

1873. Radcliffe, Arthur Henry Wright, 5 Carr's Lane, Birmingham.

1870. Radcliffe, William, Camden House, Collegiate Crescent, Sheffield.

1878. Radford, Richard Heber, 15 St. James' Row, Sheffield.

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near N
Monmouthshire.

1878. Rait, Henry Milnes, Messrs. Rait and Lindsay, Cranstonhill Fo
Glasgow; and 155 Fenchurch Street, London, E.C.

1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.

1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.

1878. Ramsden, Robert, 177 Kingsland Road, London, E.

1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W.

1869. Ransome, Robert Charles, Messrs. Ransomes Sims and Head,
Works, Ipswich.

1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Watersid
Works, Ipswich.

1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Wa
Iron Works, Ipswich; and 5 Westminster Chambers, Victoria
Westminster, S.W.

1867. Ratliffe, George, Mersey Steel and Iron Works, Caryl Street, Liverpo

2. **Ravenhill**, John R., 27 Courtfield Gardens, South Kensington, London, S.W.

2. **Rawlins**, John, Manager, Metropolitan Railway Carriage and Wagon Works, Saltley, Birmingham.

8. **Rawlinson**, Robert, C.B., Chief Inspector, Local Government Board, Whitehall, London, S.W.

0. **Reed**, Sir Edward James, K.C.B., M.P., F.R.S., Broadway Chambers, Westminster, S.W.

9. **Rennie**, George Banks, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 20 Lowndes Street, Lowndes Square, London, S.W.

8. **Rennie**, John, Metropolitan Buildings, 63 Queen Victoria Street, London, E.C.

9. **Rennie**, John Keith, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.

6. **Restler**, James William, Assistant Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E.

2. **Reynolds**, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

). **Reynolds**, George Bernard, Assistant Manager, Warda Coal State Railway, Warora, Central Provinces, India: (or care of Messrs. Stilwell, 22 Arundel Street, Strand, London, W.C.)

5. **Rich**, William Edmund, Engineer, Messrs. Eastons and Anderson, 3 Whitehall Place, London, S.W.

6. **Richards**, Edward Windsor, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough.

6. **Richards**, Josiah, Pontypool Iron and Tinplate Works, Pontypool.

3. **Richardson**, The Hon. Edward, C.M.G., Minister of Public Works, Christchurch, Canterbury, New Zealand.

5. **Richardson**, John, Methley Park, near Leeds.

3. **Richardson**, John, Engineer to Messrs. Robey and Co., Perseverance Iron Works, Lincoln.

9. **Richardson**, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

4. **Riches**, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff.

8. **Rickaby**, Alfred Austin, Bloomfield Engine Works, Sunderland.

9. **Ridley**, James Cartmell, Queen Street, Newcastle-on-Tyne.

3. **Rigby**, Samuel, Messrs. Armitage and Rigbys, Cock Hedge Mill, Warrington.

4. **Riley**, James, General Manager, Steel Company of Scotland, 150 Hope Street, Glasgow.

1879. Rixom, Alfred John, Superintendent Colonial Section, School of Practi[cal] Engineering, Crystal Palace, Sydenham, S.E.

1879. Roberts, Thomas Herbert, Assistant Mechanical Superintendent, Gra[nd] Trunk Railway, Brockville, Ontario, Canada.

1879. Robertson, Duncan, Principal Surveyor for Scotland, Underwriters' Regis[ter] for Iron Vessels, 30 Gordon Street, Glasgow.

1848. Robertson, Henry, M.P., Great Western Railway, Shrewsbury; a[nd] 13 Lancaster Gate, London, W.; and Palé, Corwen.

1879. Robertson, William, Messrs. Boyd and Co., Engineers and Shipbuilders Shanghai, China: (or care of Donald Nicolson, New Zealand Chambers, 34 Leadenhall Street, London, E.C.)

1874. Robinson, Henry, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1876. Robinson, James Salkeld, Messrs. Thomas Robinson and Son, Rochdale.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood Hall, Leek, near Stoke-upon-Trent.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1866. Robson, Thomas, Mining Engineer, Lumley Thicks, Fence Houses.

1879. Rodger, William, 7 Rampart Row, Bombay.

1872. Rofe, Henry, Resident Engineer, Nottingham Water Works, St. Peter's Gate, Nottingham; and 111 Forest Road West, Nottingham.

1868. Rogers, William, East London and Queenstown Railway, Queenstown, Cape of Good Hope: (or care of J. Kenyon Rogers, 9A Tower Chambers, Liverpool.)

1878. Rolfe, Charles Spencer, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1871. Rollo, David, Messrs. David Rollo and Sons, Fulton Engine Works, 10 Fulton Street, Liverpool.

1867. Rose, Henry Fullwood, Albert Iron Works, Moxley, near Wednesbury.

1867. Rose, Thomas, Machine Works, 37 Victoria Street, Manchester.

1874. Ross, John Alexander George, 34 Collingwood Street, Newcastle-on-Tyne.

1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.

1878. Routh, William Pole, 25 Rua de S. Francisco, Oporto, Portugal: (or care of Cyril E. Routh, 30 Jewry Street, Crutched Friars, London, E.C.)

1880. Routledge, Thomas, Ford Paper Works, Sunderland; and Claxheugh, Sunderland.

1860. Rumble, Thomas William, Chief Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E. (*Life Member.*)

1878. **Russell**, The Hon. William, George Town, Demerara; and 65 Holland Park, London, W.

1867. **Ruston**, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1877. **Rutter**, Edward, Messrs. Seaward and Co., Canal Iron Works, Millwall, London, E.

1866. **Ryland**, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. **Sacré**, Alfred Louis, 60 Queen Victoria Street, London, E.C.

1859. **Sacré**, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Manchester.

1868. **Sacré**, Edward Antoine, 26 Parliament Street, Westminster, S.W.

1864. **Said**, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)

1859. **Salt**, George, Sir Titus Salt, Bart., Sons and Co., Saltaire, near Bradford.

1874. **Sampson**, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.

1864. **Samuda**, Joseph D'Aguilar, Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.

1865. **Samuelson**, Bernhard, M.P., Britannia Iron Works, Banbury; and 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1871. **Sanders**, Richard David, Oak Mount, 128 Hagley Road, Birmingham.

1864. **Sanderson**, John, South End, Wigton.

1874. **Sauvée**, Albert, 22 Parliament Street, Westminster, S.W.

1880. **Saxby**, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1869. **Scarlett**, James, Messrs. E. Green and Son, 14 St. Ann's Square, Manchester.

1880. **Schram**, Richard, 9 Northumberland Street, Strand, London, W.C.

1876. **Scott**, David, Dacca, Bengal, India: (or care of Oriental Bank Corporation, Calcutta.)

1875. **Scott**, Frederick Whitaker, Messrs. Scott Brothers, Wire and Hemp Rope Works, West Gorton, Manchester.

1868. **Scott**, George Lamb, 46 Lancaster Avenue, Fennel Street, Manchester.

1877. **Scott**, Irving M., Messrs. Prescott Scott and Co., Union Iron Works, San Francisco, California.

1861. **Scott**, Walter Henry, Park Road, East Molesey, Kingston-on-Thames.

1868. **Scriven**, Charles, Messrs. Scriven and Holdsworth, Leeds Old Foundry, Marsh Lane, Leeds.

1864. **Seddon**, John, 98 Wallgate, Wigan.

1872. Shanks, Arthur, Messrs. A. Burn and Co., Engineers and Contrac
7 Hastings Street, Calcutta.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1875. Sharp, Thomas Budworth, Managing Engineer, Muntz Metal W
Birmingham.

1867. Sharpe, Charles James, 27 Great George Street, Westminster, S.W.

1869. Sharrock, Samuel, Windsor Iron Works, Garston, near Liverpool;
110 Cannon Street, London, E.C.

1864. Shaw, Duncan, Mining Engineer, Cordoba, Spain.

1879. Shaw, Henry Selby Hele, Assistant to Professor of Engineering, Univ
College, Bristol.

1856. Shelley, Charles Percy Bysshe, 45 Parliament Street, Westmi
S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foun
17 York Street, Liverpool.

1872. Shoolbred, James Nelson, 3 Westminster Chambers, Victoria St
Westminster, S.W.

1859. Shuttleworth, Joseph, Messrs. Clayton and Shuttleworth, Stamp End
Works, Lincoln.

1851. Siemens, Charles William, D.C.L., F.R.S., 12 Queen Anne's G
Westminster, S.W.; and 3 Palace Houses, Bayswater Road, London,

1871. Simon, Henry, 7 St. Peter's Square, Manchester.

1877. Simonds, William Turner, Messrs. J. C. Simonds and Son, Oil Mills, Bo
(*Life Member.*)

1873. Simpson, Alfred, Denmark House, Alexandra Road, St. John's W
near Hull.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 35 Comme

Slater, Isaac, Gloucester Wagon Works, Gloucester.

Slaughter, Edward, 4 Clifton Park, Clifton, Bristol.

Smethurst, William, Messrs. Dewhurst Hoyle and Smethurst, Garswood Hall Colliery, Ashton, near Wigan.

Smith, Allison Dalrymple, Locomotive Superintendent, Canterbury Railways, Christchurch, New Zealand.

Smith, Charles, Manager, Messrs. Thomas Richardson and Sons, Hartlepool Iron Works, Hartlepool.

Smith, Charles Hubert, Engineer and Shipwright Surveyor to the Board of Trade, St. Katharine Dock House, Tower Hill, London, E.

Smith, Edward Fisher, The Priory Offices, Dudley.

Smith, George Fereday, Grovehurst, Tunbridge Wells.

Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill.

Smith, John, Brass Foundry, Traffic Street, Derby

Smith, John, Messrs. Thomas Robinson and Son, Rochdale.

Smith, Josiah Timmis, Hæmatite Iron and Steel Works, Barrow-in-Furness.

Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax.

5. Smith, William, Messrs. William Smith and Sons, Partick Engine Works, Glasgow.

3. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

9. Sokoloff, Major-General Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)

8. Sopwith, Thomas, Mining Engineer, 6 Great George Street, Westminster, S.W.

7. Soyres, Francis Johnstone de, Messrs. Bush and De Soyres, Bristol Iron Foundry, Bristol.

Speck, Thomas Samuel, Resident Engineer and Locomotive Superintendent, Metropolitan District Railway, Lillie Bridge Works, West Brompton, London, S.W.

Spencer, Alfred G., Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

Spencer, George, Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

Spencer, John, Vulcan Tube Works, Westbromwich.

Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.

Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.

1866. Stephens, John Classon, Messrs. Stephens and Co., Vulcan Iron W Sir John Rogerson's Quay, Dublin.

1874. Stephens, Michael, Locomotive Superintendent, Cape Gover Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, 9 Victoria Chambers, Victoria Westminster, S.W.

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, Throgm Street, London, E.C.

1876. Sterne, Louis, Messrs. Thomson Sterne and Co., Crown Iron W Glasgow; and 9 Victoria Chambers, Victoria Street, Westminster,

1875. Stevens, Arthur James, Uskside Iron Works, Newport, Monmouthshi

1878. Stevenson, George Wilson, 4 Westminster Chambers, Victoria S Westminster, S.W.

1877. Stewart, Alexander, Manager, Messrs. Thwaites Brothers, Vulcan Works, Thornton Road, Bradford.

1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas W Manchester; and Silwood Park, Sunninghill, near Staines.

1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Works, Glasgow.

1851. Stewart, John, Blackwall Iron Works, Poplar, London, E.

1880. Stirling, James, Locomotive Superintendent, South Eastern Rail Ashford.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Rail Doncaster.

1875. Stoker, Frederick William, Manager, Messrs. Johnson and Reay, Moor Iron Works, Stockton-on-Tees.

1877. Stokes, Alfred Allen, Chief Assistant Locomotive Superintendent, Indian Railway, Jumalpore, Bengal; (or care of Messrs. W. and

865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton; and Bosvigo, Preston Park, Brighton.

873. Strype, William George, The Murrough, Wicklow.

1861. Sumner, William, 2 Brazennose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1860. Swindell, James Evers, Parkhead Iron Works, Dudley; and Oldswinford, near Stourbridge.

1864. Swindell, James Swindell Evers, Queen's Chambers, 8 Cherry Street, Birmingham; and Clent House, Stourbridge.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.

1875. Tangye, George, Messrs. Tangye Brothers, Cornwall Works, Soho, Birmingham.

1861. Tangye, James, Messrs. Tangye Brothers, Cornwall Works, Soho, Birmingham; and Aviary Cottage, Illogan, near Redruth.

1879. Tartt, William, Superintending Engineer, Euphrates and Tigris Steam Navigation Company, Bussora and Bagdad: (or care of William Cole, 35 Grove Road, Regent's Park, London, N.W.)

1876. Taunton, Richard Hobbs, Messrs. Taunton and Hayward, Star Tube Works, Heneage Street, Birmingham.

1874. Taylor, Henry Enfield, Mining Engineer, 15 Newgate Street, Chester.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.

1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1867. Taylor, Joseph, Corinthian Villa, Acock's Green, near Birmingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 99 Constitution Hill, Birmingham.

1874. Taylor, Percyvale, Panther Lead Smelting Works, Avon Street, St. Philip's, Bristol.

1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1876. Taylor, William Henry Osborne, Panteg Steel and Engineering Works, Panteg, near Pontypool.

1864. Tennant, Charles, M.P., The Glen, Innerleithen, near Edinburgh. (*Life Member.*)

1877. Thom, William, Messrs. W. and J. Yates, Canal Foundry, Blackburn.

1867. Thomas, Joseph Lee, 16 Holland Road, Kensington, London, W.

1864. Thomas, Thomas, 19 The Parade, Cardiff.
1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.
1875. Thompson, John, Highfields Boiler Works, Ettingshall, near Wolverhampton.
1857. Thompson, Robert, Victoria Chambers, Wigan; and Standish, near Wigan.
1880. Thompson, Thomas William, Messrs. Thompson and Gough, South Mersey Ferries, Birkenhead.
1862. Thompson, William, 116 Fenchurch Street, London, E.C.
1875. Thoms, George Eastlake, Borough Engineer, Town Hall, Wolverhampton
1879. Thomson, David, Messrs. R. Moreland and Son, 3 Old Street, St. Luke's London, E.C.
1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.
1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.
1880. Thornbery, William Henry, Jun., 45 Bull Street, Birmingham.
1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works Burton-on-Trent.
1877. Thornton, Frederic William, Hydraulic Engineering Co., 7 Drapers Gardens, Throgmorton Avenue, London, E.C.
1876. Thornycroft, John Isaac, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.
1875. Thwaites, William Henry, Messrs. Thwaites Brothers, Vulcan Iron Works, Thornton Road, Bradford.
1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1857. Tomlinson, Joseph, Jun., Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Chapel Street Works, Edgware Road, London, N.W.
1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.
1876. Trevithick, Richard Francis, Locomotive Engineer, Central Argentine Railway, Rosario, Argentine Republic: (or care of M. Trevithick, The Cliff, Penzance.)
1873. Trow, Joseph, Messrs. William Trow and Sons, Union Foundry, Wednesbury; and Holyhead Road, Wednesbury.
1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich.
1876. Turney, John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham.
1872. Turton, Thomas, Liverpool Forge Company, Brunswick Dock, Liverpool.
1867. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W.

Tyler, Sir Henry Whatley, K.C.B., M.P., Pymmes Park, Edmonton, Middlesex.

Tylor, Joseph John, 4 Storey's Gate, Westminster, S.W.

Tyson, Isaac Oliver, Ousegate Iron Works, Selby.

Unsworth, Thomas, 14 Marsden Street, Brown Street, Manchester.

. **Unwin,** William Cawthorne, Professor of Engineering, Royal Indian Engineering College, Cooper's Hill, Staines.

. **Upward,** Alfred, 8 Queen Anne's Gate, Westminster, S.W.

. **Urquhart,** Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Russia: (or care of John Maclachlan, 15 Hamilton Street, Greenock).

). **Valon,** William Andrew McIntosh, Engineer, Ramsgate Local Board, Hardres Street, Ramsgate.

2. **Vavasseur,** Josiah, 28 Gravel Lane, Southwark, London, S.E.

5. **Vickers,** Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

51. **Vickers,** Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

56. **Waddington,** John, 35 King William Street, London Bridge, London, E.C.

79. **Wadia,** Nowrosjee Nesserwanjee, Manager, Manockjee Petit Manufacturing Co., Tardeo, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.)

75. **Wailes,** John William, Patent Shaft Works, Wednesbury.

5. **Wainwright,** William, Midland Railway, Carriage and Wagon Department, Derby.

3. **Wakefield,** John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.

3. **Waldenström,** Eric Hugo, Manager, Broughton Copper Works, Broughton Road, Manchester.

2. **Walker,** Alexander, 6 Llwyn Terrace, Oswestry.

). **Walker,** Alfred, Albion Iron Works, Aldwark, York.

7. **Walker,** Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1. **Walker,** Bernard Peard, Eagle Foundry, Broad Street, Birmingham.

7. **Walker,** Charles Clement, Midland Iron Works, Donnington, near Newport, Shropshire; and Lilleshall Old Hall, near Newport, Shropshire.

1877. Walker, David, Superintendent of Engineering Workshops, King's Colleg
Strand, London, W.C.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefiel
Iron Works, Wigan.

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Stree
Birmingham.

1878. Walker, William, Kaliemaas, Palace Road, West Dulwich, London
S.E.

1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iro
Works, Sheffield.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1865. Waller, George Arthur, Messrs. A. Guinness Son and Co., St. James' Gat
Brewery, Dublin.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway,
Montreal, Canada.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works
Dublin.

1877. Walton, James, 28 Maryon Road, Charlton.

1876. Ward, William Meese, Limerick Foundry, Great Bridge, Tipton.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, nea
Birmingham.

1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyn
Engine Works, Hunslet, Leeds.

1852. Warham, John R., Messrs. Thornewill and Warham, Burton Iron Works
Burton-on-Trent.

1874. Warner, Edward, Messrs. Woods Cocksedge and Co., Suffolk Iron Works
Stowmarket.

1858. Waterhouse, Thomas, Claremont Place, Sheffield. (*Life Member.*)

1862. Watkins, Richard, Messrs. Seaward and Co., Canal Iron Works, Millwall
London, E.

1866. Watson, Robert, Engineer, Brereton and Hayes Collieries, near Rugeley.

1879. Watson, William Renny, Messrs. Mirrlees Tait and Watson, Engineers
Glasgow.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1877. Waugh, John, Chief Engineer, Yorkshire Boiler Insurance and Steam
Users' Co., 29 Tyrrel Street, Bradford.

1878. Weatherhead, Patrick Lambert, 3 Chaussée Strasse, Berlin.

1862. Webb, Francis William, Locomotive Superintendent, London and North
Western Railway, Crewe.

1870. Weiss, Hubert August Otto, Messrs. Siemens Brothers, Telegraph Works,
Charlton, Kent.

72. Welch, Edward John Cowling, Palace Chambers, St. Stephen's, Westminster, S.W.

62. Wells, Charles, Moxley Iron and Steel Works, near Bilston.

76. West, Henry Hartley, Chief Surveyor, Underwriters' Registry for Iron Vessels, 13A Exchange Buildings, Liverpool.

74. West, Nicholas James, Messrs. Harvey and Co., Hayle Foundry, Hayle.

77. Western, Charles Robert, Messrs. Western and Co., Chaddesden Works, Derby; and Chaddesden Hill, Derby.

77. Western, Maximilian Richard, Messrs. Western and Co., Belvedere Road, Lambeth, London, S.E.

62. Westmacott, Percy Graham Buchanan, Sir William G. Armstrong and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

80. Westmoreland, John William Hudson, 228 Arkwright Street, Nottingham.

67. Weston, Thomas Aldridge, care of J. C. Mewburn, 169 Fleet Street, London, E.C.; and 5 Bedford Terrace, Harpur Street, Bedford.

30. Westwood, Joseph, Jun., Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

7. Wheatley, Thomas, Manager, Wigtownshire Railway, Wigtown, Wigtownshire.

6. Wheeldon, Frederick R., Highfields Engine Works, Bilston; and 16 Waterloo Road South, Wolverhampton.

4. White, Henry Watkins, Chief Engineer, H.M. Dockyard, Simon's Town, Cape of Good Hope.

4. White, Isaias, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly.)

6. Whiteley, William, Messrs. William Whiteley and Sons, Prospect Iron Works, Lockwood, Huddersfield.

9. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.

3. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

55. Whitley, Joseph, Railway Works, Hunslet Road, Leeds.

69. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

47. Whitworth, Sir Joseph, Bart., D.C.L., LL.D., F.R.S., 44 Chorlton Street, Portland Street, Manchester; and Stancliffe, Matlock Bath.

59. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford.

78. Wicks, Henry, Superintendent, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India.

78. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

8. Wigram, Reginald, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1877. Wilkinson, Robert, Engineer, Lima Water Works, Lima, Peru: (c
Messrs. Bates Stokes and Co., Water Street, Liverpool.)

1874. Williams, David, Manager, Pontypool Iron and Tinplate
Pontypool.

1865. Williams, Edward, Cleveland Lodge, Middlesbrough.

1847. Williams, Richard, Patent Shaft Works, Wednesbury.

1859. Williams, Richard Price, 38 Parliament Street, Westminster, S.W

1873. Williams, William Lawrence, Messrs. Proctor and Williams, St
and Talbot Engine Works, Tustin Street, Old Kent Road, Lon

1870. Willman, Charles, Exchange Place, Middlesbrough.

1878. Wilson, Alexander, Messrs. Wilson Cammell and Co., Steel
Dronfield, near Sheffield.

1872. Wilson, Alfred, Messrs. Howson and Wilson, 2 Exchange
Middlesbrough.

1859. Wilson, George, Messrs. Charles Cammell and Co., Cyclops Steel
Works, Sheffield.

1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.

1863. Wilson, John Charles, 5 Westminster Chambers, Victoria
Westminster, S.W.

1879. Wilson, Joseph William, Principal of School of Practical Engi
Crystal Palace, Sydenham, S.E.

1857. Wilson, Robert, F.R.S.E., Messrs. Nasmyth Wilson and Co., Bri
Foundry, Patricroft, near Manchester.

1880. Wilson, Robert, 116 Queen Victoria Street, London, E.C.

1873. Wilson, Thomas Sipling, care of Messrs. James Bischoff and
St. Helen's Place, London, E.C.

1867. Winby, Frederick Charles, 1 College Street, Nottingham.

1872. Winstanley, Robert, Mining Engineer, 32 St. Ann's Street, Manche

1859. Winter, Thomas Bradbury, 53 Moorgate Street, London, E.C.

1872. Wise, William Lloyd, 7 Whitehall Place, London, S.W.

1871. Withy, Edward, Messrs. Withy and Co., Middleton Iron Ship
Yard, West Hartlepool.

1878. Wolfe, John Edward, Arthington, Torquay.

1878. Wolfenden, Richard, Chief Engineer, Chinese Revenue Steame
Feiy," Shanghai, China: (or care of Frederick Degenaer, Zetlan
Hong Kong, China.)

1878. Wolfenden, Robert, Engineer and Millwright, Shanghai, China:
of Frederick Degenaer, Zetland Street, Hong Kong, China.)

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street

1876. Wood, Thomas, Mining Engineer, North Hetton Collieries,
Houses.

1873. Woodhead, John Proctor, 54 John Dalton Street, Manchester.

1874. **Worsdell**, Thomas William, London and North Western Railway, Locomotive Department, Crewe.

1877. **Worssam**, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N.

1876. **Worssam**, Samuel William, Oakley Works, King's Road, Chelsea, London, S.W.

1860. **Worthington**, Samuel Barton, Resident Engineer, London and North Western Railway, Victoria Station, Manchester; and 12 York Place, Oxford Road, Manchester.

1866. **Wren**, Henry, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.

1870. **Wright**, George Benjamin, Goscote Iron Works, near Walsall.

1878. **Wright**, George Howard, Mining Engineer, 12 Trumpington Street, Cambridge.

1876. **Wright**, James, Messrs. Ashmore and While, Hope Iron Works, Bowesfield, Stockton-on-Tees.

1867. **Wright**, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.

1867. **Wright**, John Turner, Universe Rope Works, Garrison Street, Birmingham.

1859. **Wright**, Joseph, Metropolitan Railway Carriage and Wagon Co., Saltley Works, Birmingham; and 85 Gracechurch Street, London, E.C.

1860. **Wright**, Joseph, Neptune Forge, Chain and Anchor Works, Tipton; and 45 Islington Row, Edgbaston, Birmingham.

1863. **Wright**, Owen, Broadwell Forge, Oldbury, near Birmingham.

1878. **Wright**, William Barton, Locomotive Superintendent, Lancashire and Yorkshire Railway, Victoria Station, Manchester.

1871. **Wrightson**, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1865. **Wyllie**, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1877. **Wyvill**, Frederic Christopher, 46 Schiller Strasse, Hannover.

1878. **Yates**, Henry, Brantford, Ontario, Canada.

1880. **Yates**, William, Locomotive Works, Lancashire and Yorkshire Railway, Miles Platting, Manchester.

1879. **Yeomans**, David Maitland, 13 Lexham Gardens, Cromwell Road, London, W.

1879. **Young**, George Scholey, Messrs. T. A. Young and Son, Orchard Place, Blackwall, London, E.

1874. **Young**, James, Managing Engineer, Lambton Colliery Works, Fence Houses.

1879. **Young**, James, Low Moor Iron Works, near Bradford.

1861. Yule, William, Messrs. J. H. Young and Co., 53 Mill Street, B
Glasgow.

1880. Ziffer, Ferdinand Henry, Messrs. Ziffer and Walker, Boston
Oxford Street, Manchester.

ASSOCIATES.

1880. Allen, William Edgar, Well Meadow Steel Works, Sheffield.
1880. Bagshawe, Washington, Messrs. John Spencer and Sons, Newbu
Works, Newcastle-on-Tyne.
1867. Blinkhorn, William, London and Manchester Plate Glass Works
St. Helen's.
1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duk
Stamford Street, London, S.E.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. H
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1863. Forster, George Emmerson, Contractor's Office, Washington,
Durham.
1865. Gössell, Otto, 41 Moorgate Street, London, E.C.
1878. Grosvenor, The Right Hon. Lord Richard De Aquila, M.P., 1
Brook Street, Grosvenor Square, London, W.
1880. Haggie, David Henry, Wearmouth Rope Works, Sunderland.
1874. Hardcastle, Robert Anthony, Monk Bridge Iron Works, Leeds.
1874. Hurman, James, Traffic Superintendent, Taff Vale Railway,
and 44 Charles Street, Cardiff.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds.
Associate.)
1865. Longsdon, Alfred, 2 Crown Buildings, Queen Victoria Street, Lond
1860. Manby, Cordy, Messrs. Moore and Manby, Castle Street, Dudley.
1868. Matthews, Thomas Bright, Messrs. Turton Brothers and M
Phœnix Steel Works, Sheffield.
1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountn
Cannon Street, London, E.C.
1865. Parry, David, Leeds Iron Works, Leeds.
1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.
1877. Render, Frederick, Crown Corn Mills, Stanley Street, Salford, Ma
1878. Roeckner, Carl Heinrich, 4 Royal Arcade, Newcastle-on-Tyne.
1875. Schofield, Christopher J., Vitriol and Alkali Works, Clayt
Manchester.

1878. **Stuart**, James, Professor of Mechanism in Cambridge University, Trinity College, Cambridge.

1869. **Varley**, John, Farnley Iron Works, Leeds.

1877. **Vial**, Enrique de, Muelle No. 14, Santander, Spain: (or care of Messrs. Alexander Bell and Sons, 8 Finch Lane, London, E.C.)

1875. **Waslekar**, Nanaji Narayan, care of Anglo-Vernacular Press, New Nagpada, Tank Street, Bycalla, Bombay, India.

1878. **Watson**, Joseph, Attorney General's Chambers, New Court, Temple, London, E.C.

GRADUATES.

1874. **Allen**, Frank, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1880. **Anderson**, Edward William, Messrs. Eastons and Anderson, Erith Iron Works, Erith, London, S.E.

1878. **Appleby**, Charles, Jun., Messrs. Appleby Brothers, East Greenwich Works, London, S.E.

1878. **Armstrong**, Joseph, Great Western Railway Works, Swindon.

1872. **Armstrong**, Thomas, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1879. **Arteaga**, Alberto de, care of Juan J. de Arteaga, Rincon 62, Monte Video, Uruguay: (or care of Messrs. Hartog Reeves and Co., 13 Cullum Street, London, E.C.)

1879. **Bagot**, Alan Charles, Messrs. Apps and Bagot, 433 Strand, London, W.C.

1869. **Bainbridge**, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1880. **Benham**, Percy, Messrs. Benham, 50 Wigmore Street, London, W.

1880. **Birkett**, Herbert, Messrs. J. and E. Hall, Iron Works, Dartford.

1880. **Bright**, Thomas Smith, Messrs. Hutchins and Bright, Nott Square, Carmarthen; and Glannant, Carmarthen.

1878. **Brooke**, Arthur, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N.

1880. **Buckle**, William Harry Ray, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1878. **Buddicom**, Harry William, Penbedw Hall, Mold, Flintshire.

1879. **Burnet**, Lindsay, 167 St. Vincent Street, Glasgow; and 38 Albany Street, Leith.

1879. **Dady**, Jamsetjee Nesserwanjee, 4 Cawasjee Patell Street, Fort, Bombay, India.

1876. Davis, Joseph, Lancashire and Yorkshire Railway, Engineer's Offic Manchester.

1875. Dawson, Edward, The Cottage, Chilton Moor, Fence Houses.

1873. Dobson, Richard Joseph Caistor, Gemör Fabrik, Kendal, Samarang, Java (or care of Charles E. S. Dobson, 4 Chesterfield Buildings, Victori Park, Clifton, Bristol.)

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mill Bridge Street West, Summer Lane, Birmingham.

1873. Edmunds, John Sharp Wilbraham, Sheepcote Street Works, Sheepcot Street, Birmingham.

1875. Ffolkes, Martin William Brown, 28 Davies Street, Grosvenor Square London, W.

1880. Francis, Archibald Adley, Locomotive Works, Great Eastern Railway Stratford, London, E.

1879. Frossard, Charles Edouard, Atlas Iron Works, Gloucester.

1878. Greig, Alfred, Messrs. John Fowler and Co., Steam Plough and Locomotiv Works, Leeds.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works Shadwell Street, Birmingham.

1874. Hedley, Henry, Coppa Colliery, near Mold, Flintshire.

1874. Hedley, Thomas, 13 Elm Vale, Fairfield, Liverpool.

1879. Henriques, Cecil Quixam, 5 Westminster Chambers, Victoria Street Westminster, S.W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford.

1867. Holland, George, Mechanical Department, Grand Trunk Railway Montreal, Canada.

1879. Howard, J. Harold, Britannia Iron Works, Bedford.

1877. Jeffreys, Edward Homer, Monk Bridge Iron Works, Leeds: and Gipton Lodge, Leeds.

1880. Jenkins, Rhys, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and 6 Grove Terrace, Leeds.

1879. Lowthian, George, 8 Delahay Street, Westminster, S.W.

1878. Mannock, Thomas, Messrs. Higginbottom and Mannock, Crown Iron Works, Hyde Road, West Gorton, Manchester.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1867. Mitchell, John, Swaithe Colliery, Barnsley.

1868. Moor, William, Jun., Hetton Colliery, Hetton, near Fence Houses.

1872. Napier, Robert Twentyman, Yoker, Dumbartonshire.

1878. Newall, John Walker, Egerton Iron Works, Windsor Street, Salford, Manchester.

1876. Owen, George Charles Mickleburgh, Mechanical Engineer's Office, London and North Western Railway, Crewe.

1880. **Parsons**, The Hon. Charles Algernon, Sir W. G. Armstrong and Co., Elswick, Newcastle-on-Tyne; and 21 Budle Street, Newcastle-on-Tyne.

1880. **Paterson**, Walter Saunders, London Brighton and South Coast Railway, Locomotive Department, London Bridge, London, S.E.

1867. **Pearson**, John Edward, Golborne Park, near Newton-le-Willows, Lancashire.

1870. **Pearson**, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1879. **Phillips**, Robert Edward, 37 Great George Street, Westminster, S.W.

1875. **Sheppard**, Herbert Gurney, Imperial Brazilian Natal and Nova Cruz Railway, Natal, Pernambuco, Brazil: (or care of C. L. Sheppard, The Hall, Welwyn.)

1879. **Solly**, Arthur John, care of R. H. Tweddell, 14 Delahay Street, Westminster, S.W.

1877. **Spielmann**, Marion Harry, 16 Linden Gardens, Kensington Gardens, London, W.

1874. **Taylor**, Arthur, Pontgibaud Lead Works, Puy de Dôme, France; and 6 Queen Street Place, Upper Thames Street, London, E.C.

1878. **Waddington**, John, Jun., 35 King William Street, London Bridge, London, E.C.

1875. **Walker**, Arthur Henry, Guild Hall Chambers, Cardiff.

1880. **Weymouth**, Francis Marten, Mill Hill, London, N.W.

1877. **Whitelock**, William Thomas Grant, Bowling Iron Works, near Bradford.

1878. **Whytehead**, Hugh Edward, 88 West Hill, Sydenham, London, S.E.

1868. **Wicksteed**, Joseph Hartley, Well House Foundry, Meadow Road, Leeds.

1879. **Wood**, Edward Walter Naylor, Assistant Resident Engineer, Harbour Works, Holyhead.

1880. **Wood**, John Mackworth, Messrs. Henry Pontifex and Sons, Albion Works, King's Cross, London, N.

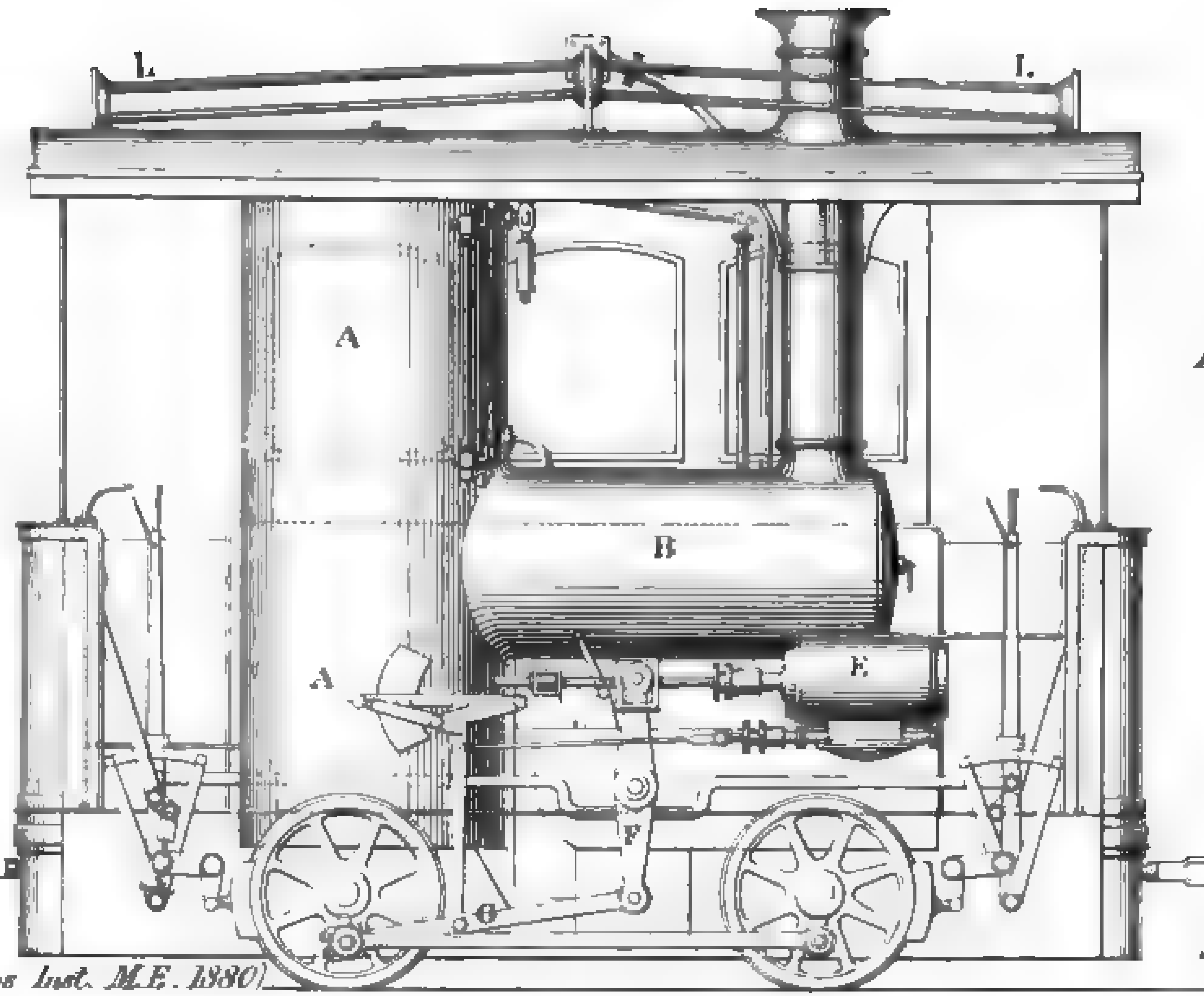
1880. **York**, Francis Colin, Rock Terrace House, Shifnal.

[redacted]

Plate 1.

Fig. 1.

Side Elevation.



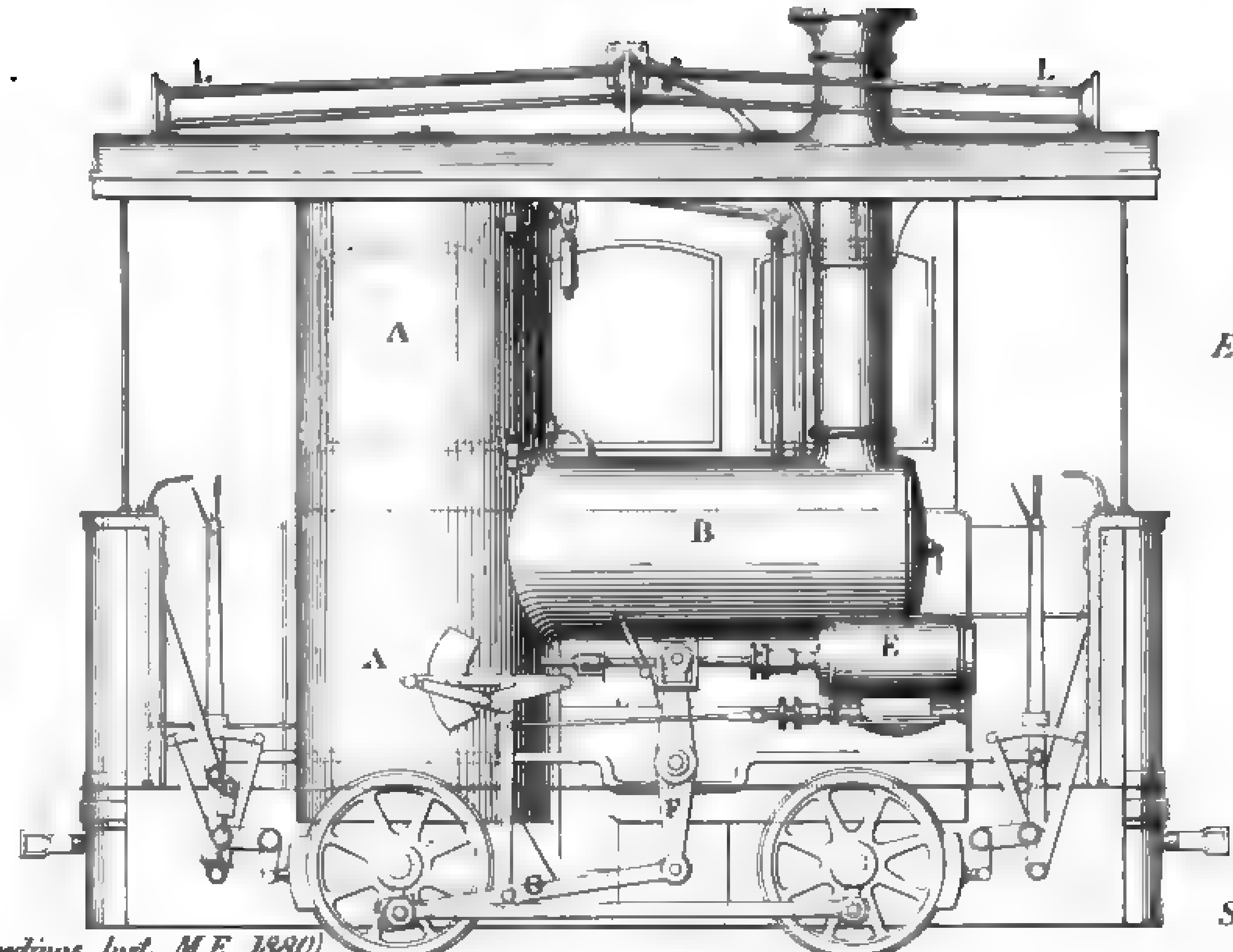
Scale 1/80th

(Proceedings Inst. M.E. 1880)

[redacted]

Plate 1.

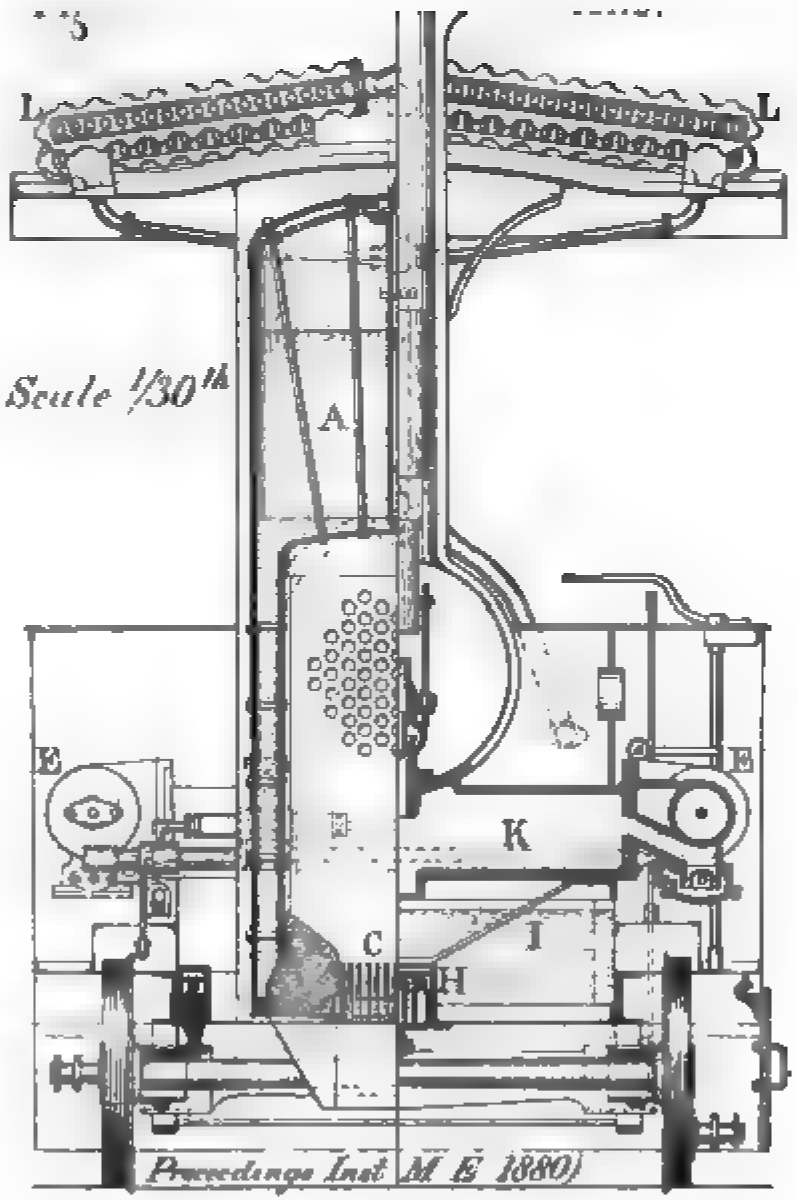
Fig. 1. Side Elevation.



Scale 1/80th

(Proceedings Inst. M.E. 1880)

Plate 3.



Scale 1/30th

Proceedings Inst M E 1880)

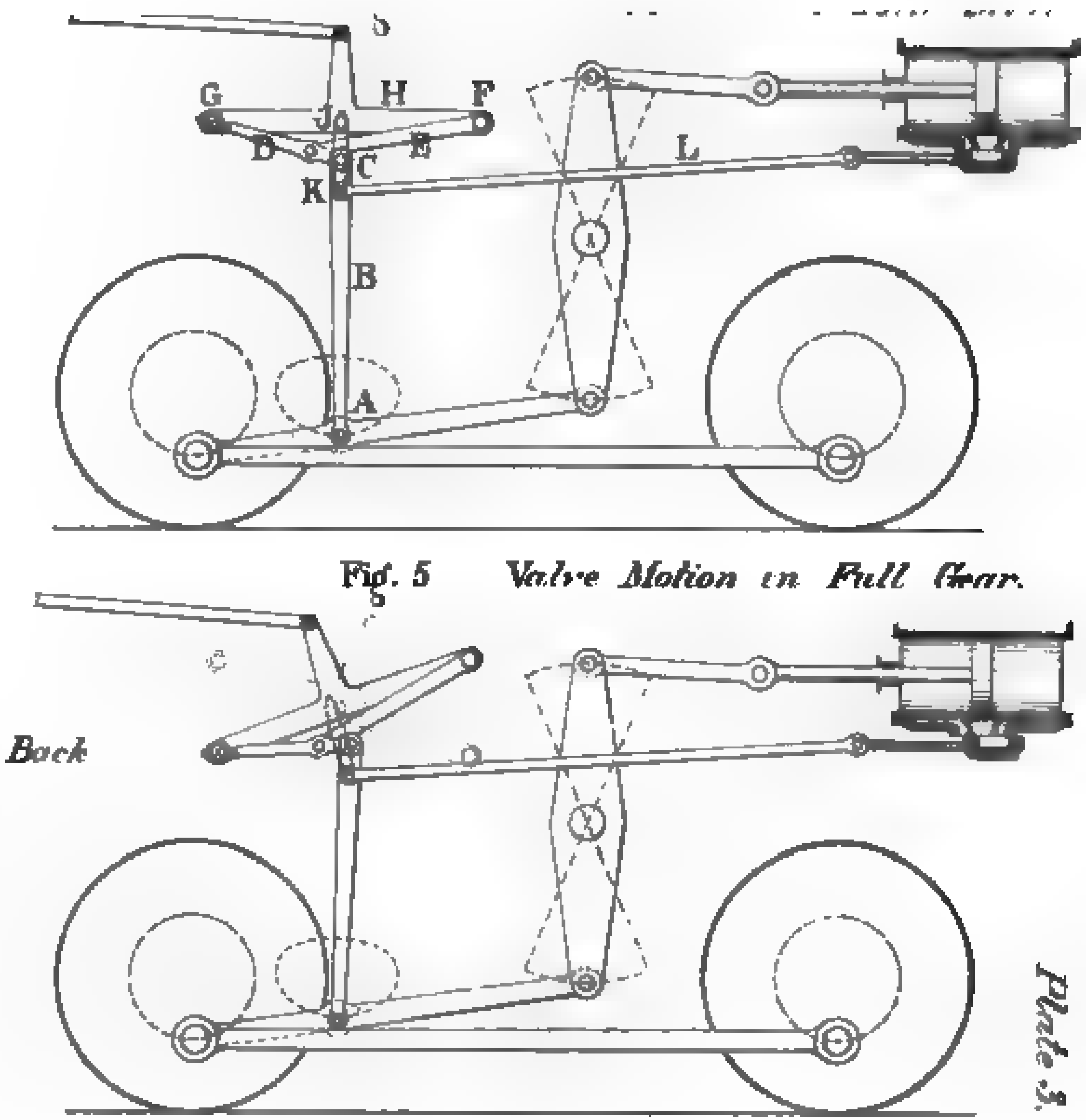
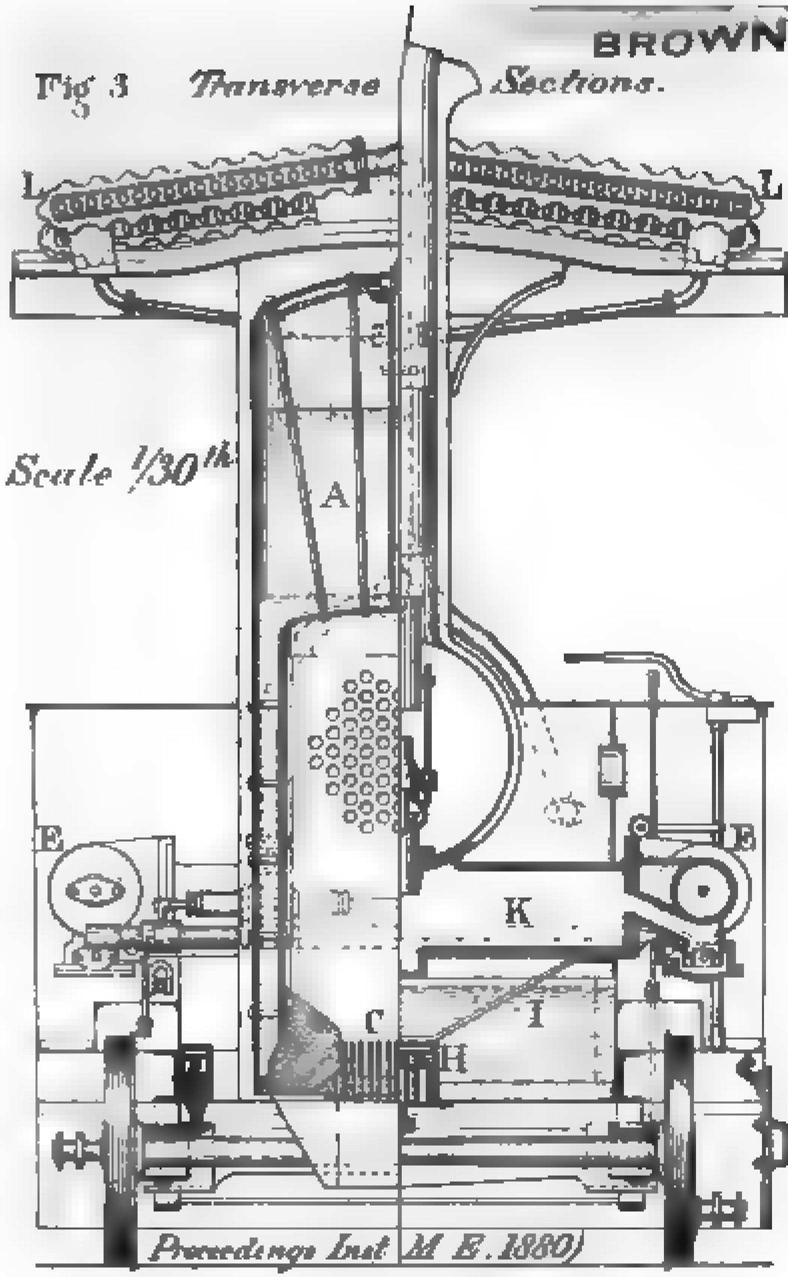


Fig. 5 Valve Motion in Full Gear.

BROWN'S TRAMWAY LOCOMOTIVE.

Plate 3.

Fig 3 Transverse Sections.



Scale 1/30th

Proceedings Inst M E. 1880)

Fig. 4. Valve Motion in Mid Gear.

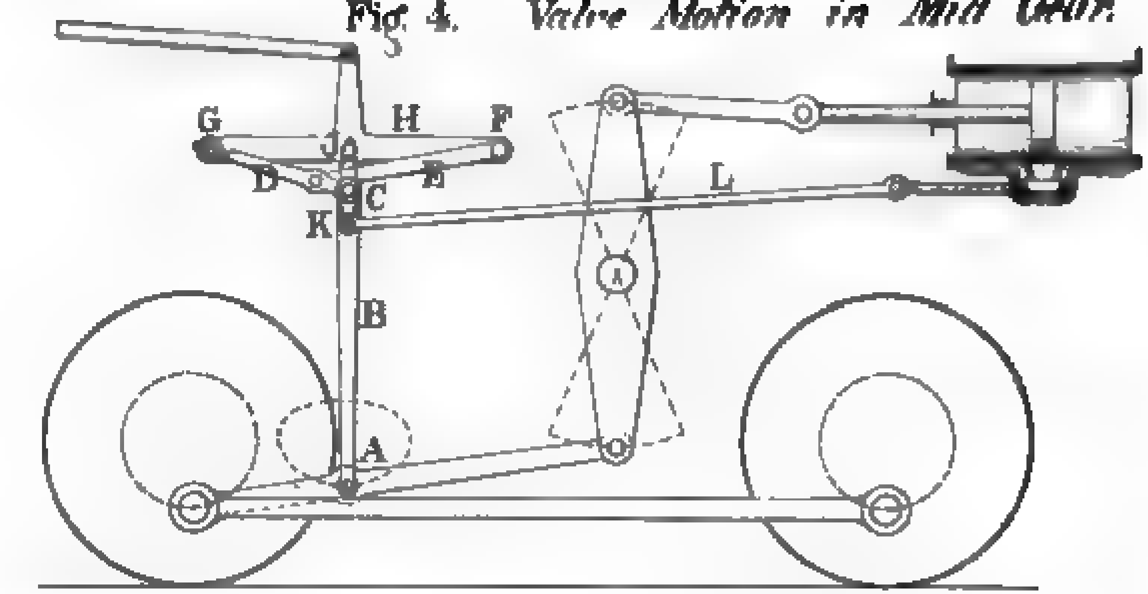


Fig. 5. Valve Motion in Full Gear.

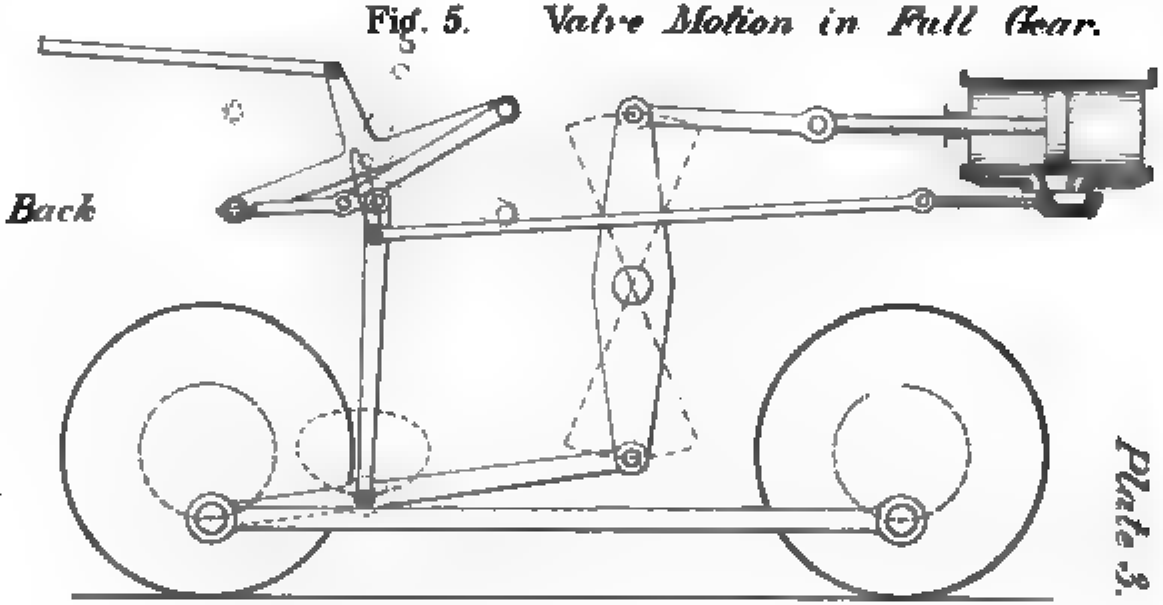


Plate 3.

PLATE ROLLING MACHINERY. *Plate 4.*

Fig. 1. *Belgian Mill, Back Elevation.*

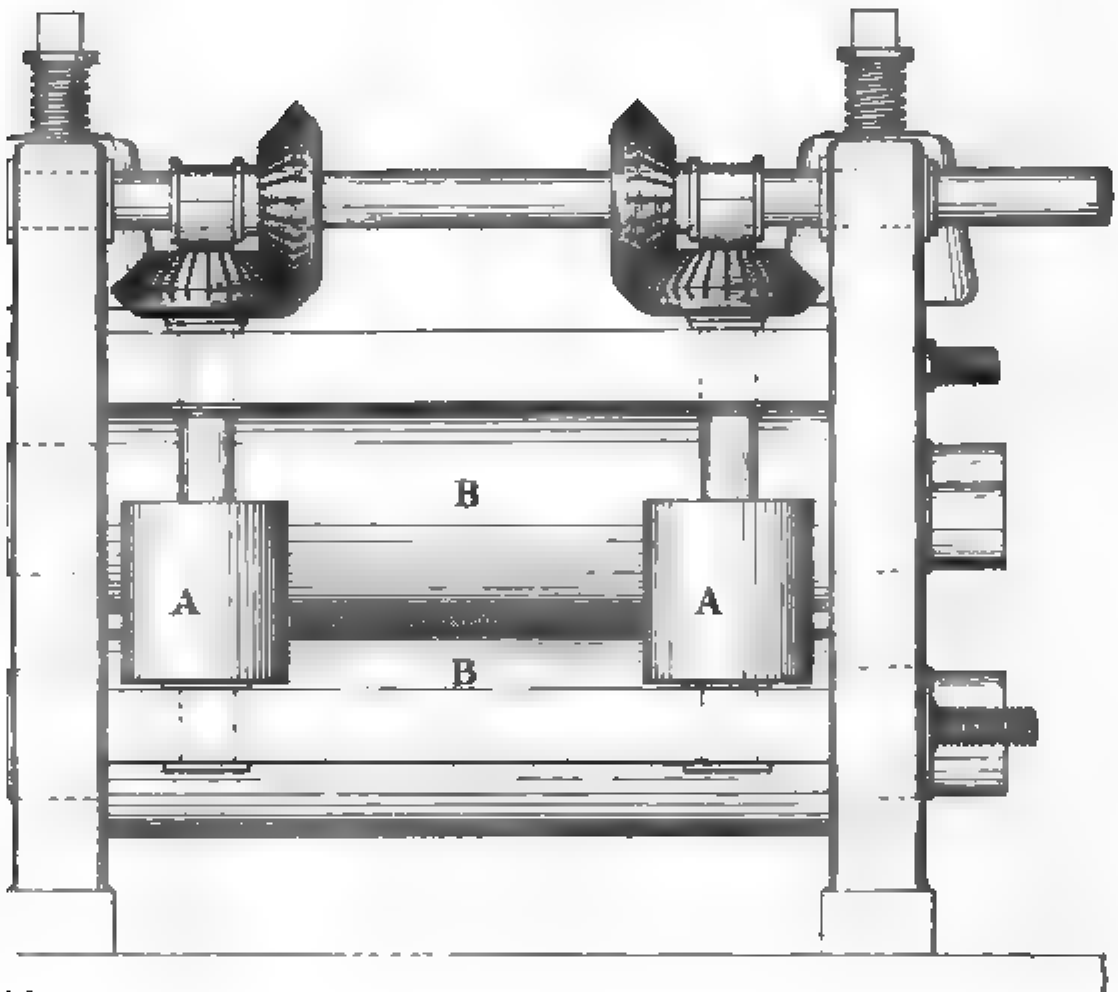
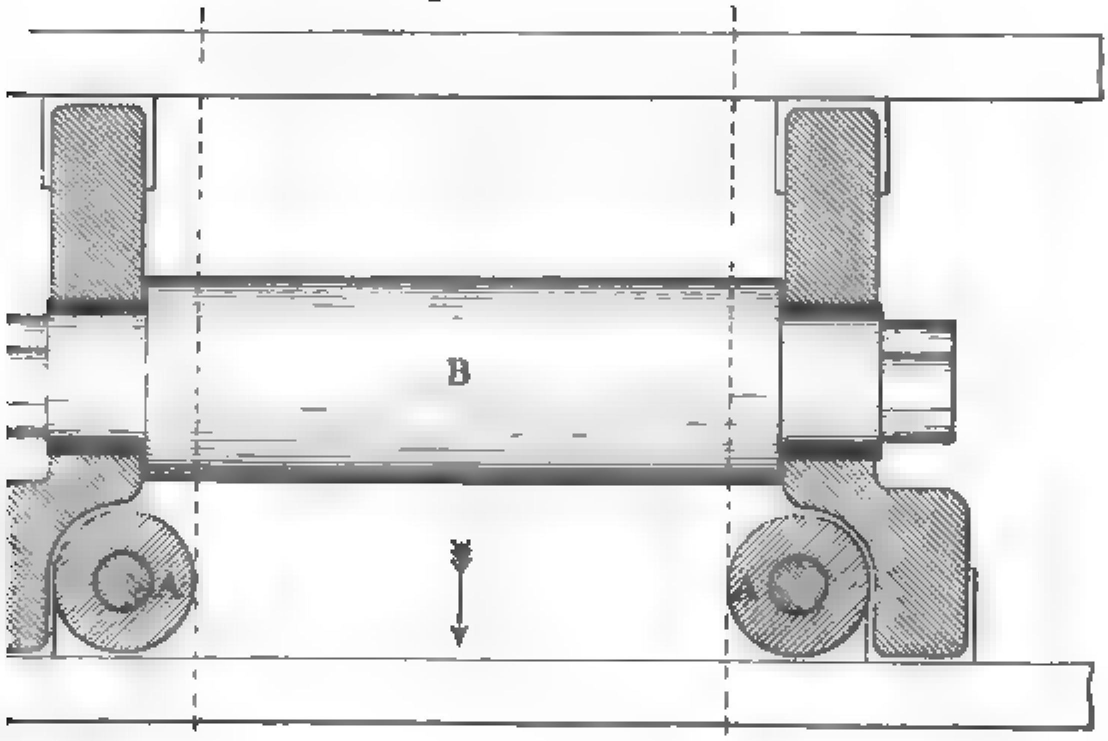


Fig. 2 *Plan of improved Belgian Mill.*



(Proceedings Inst. M.E. 1880) *Scale 1/30th.*

PLATE ROLLING MACHINERY.

Sliding Roll Mill.

Fig. 3. *Forge Rolling.*

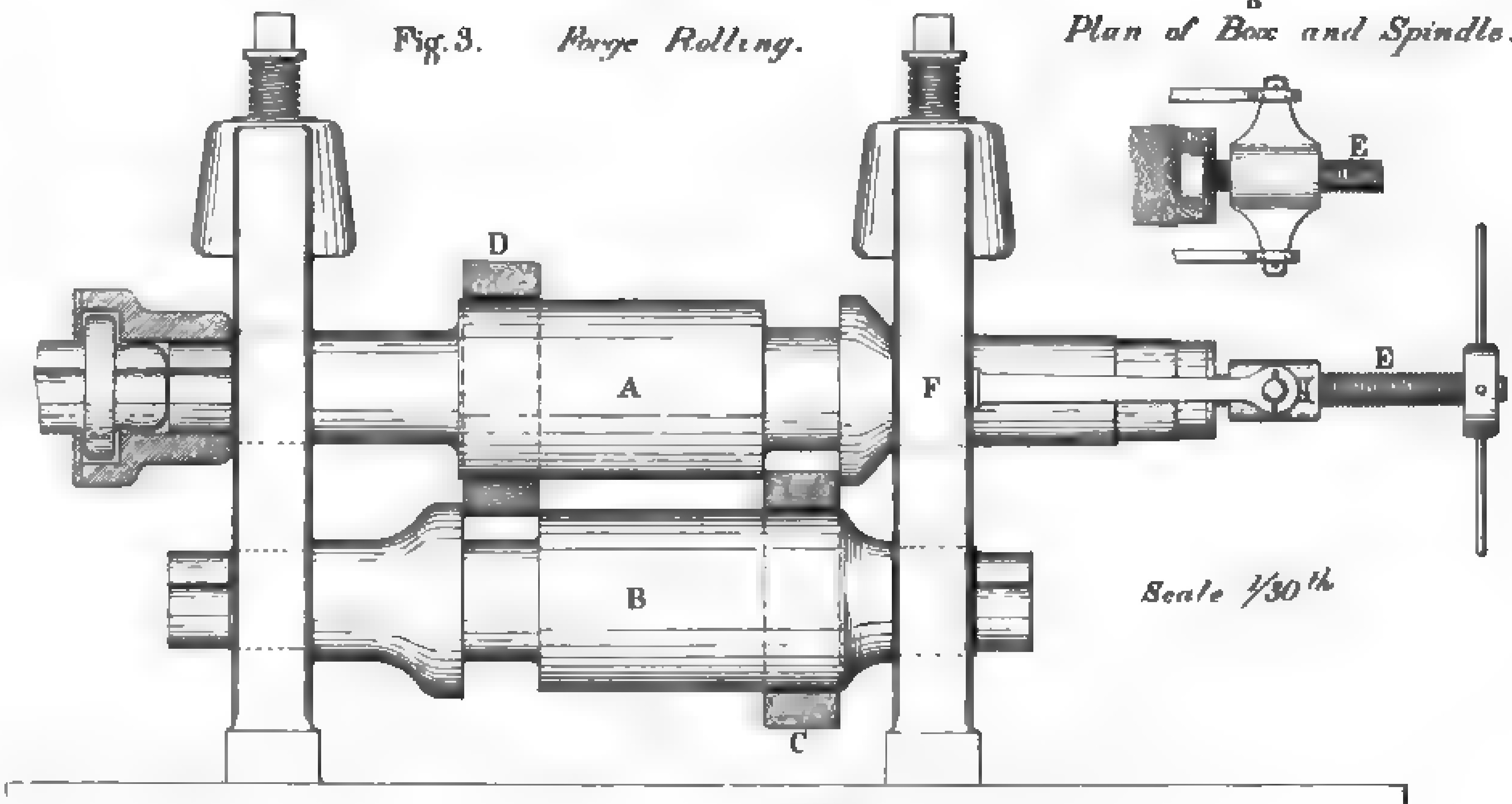


Fig. 4
Plan of Box and Spindle.

Scale 1/30th

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

Plate 5.

Plate 6.

Blooming Rolls.

Fig 5.

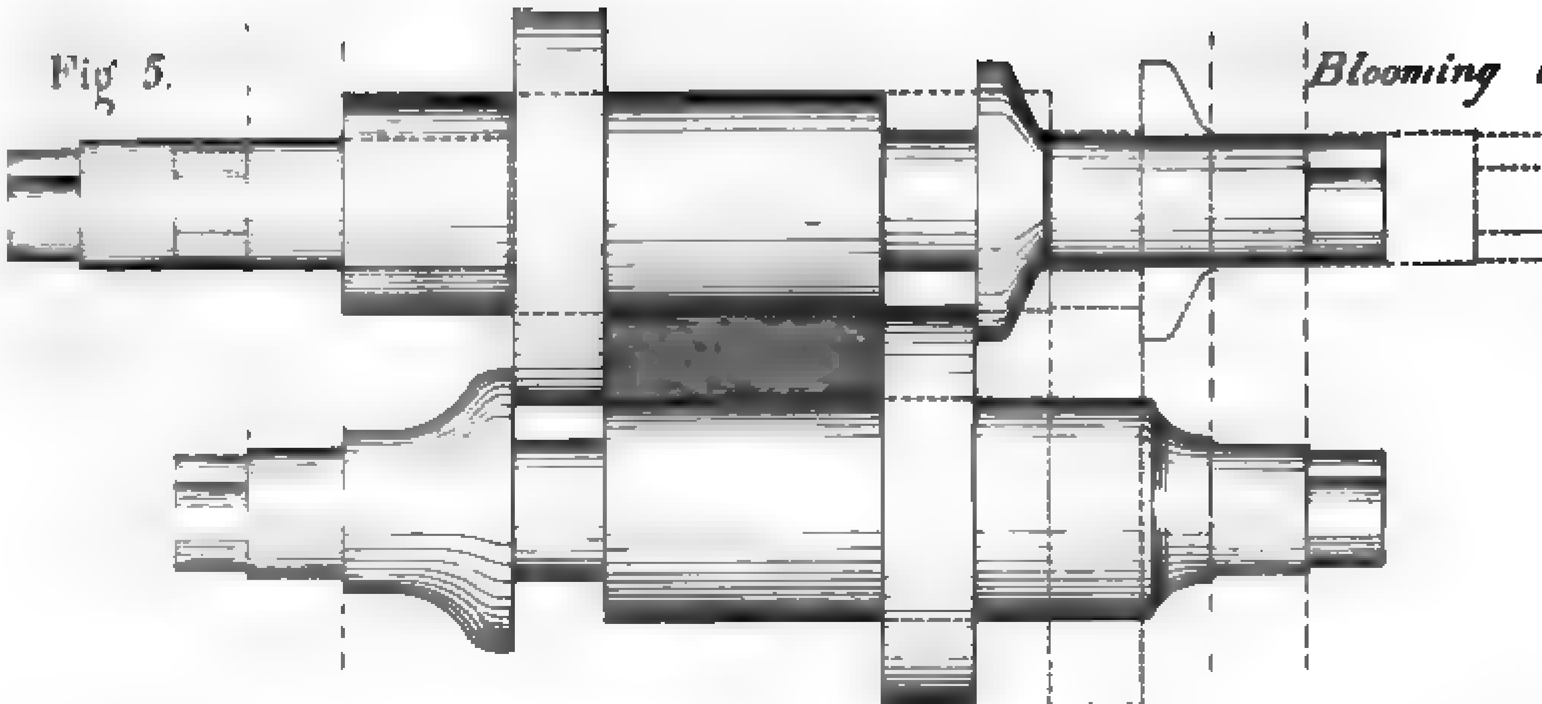
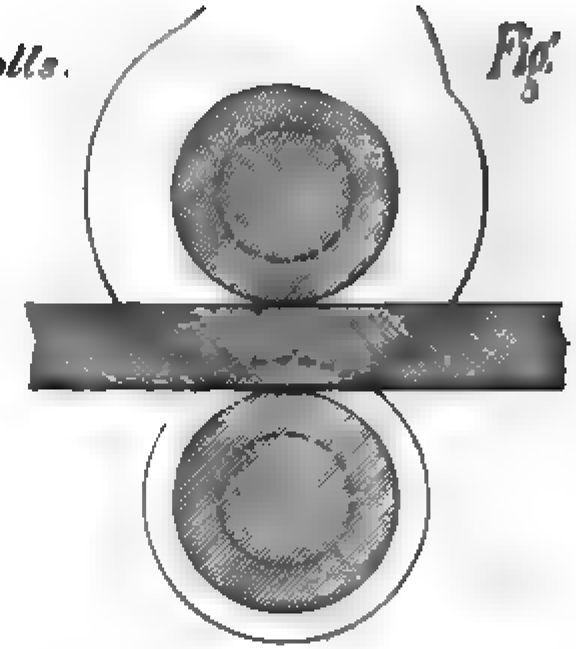


Fig. 6.



Raughing-down Rolls

Fig 7.

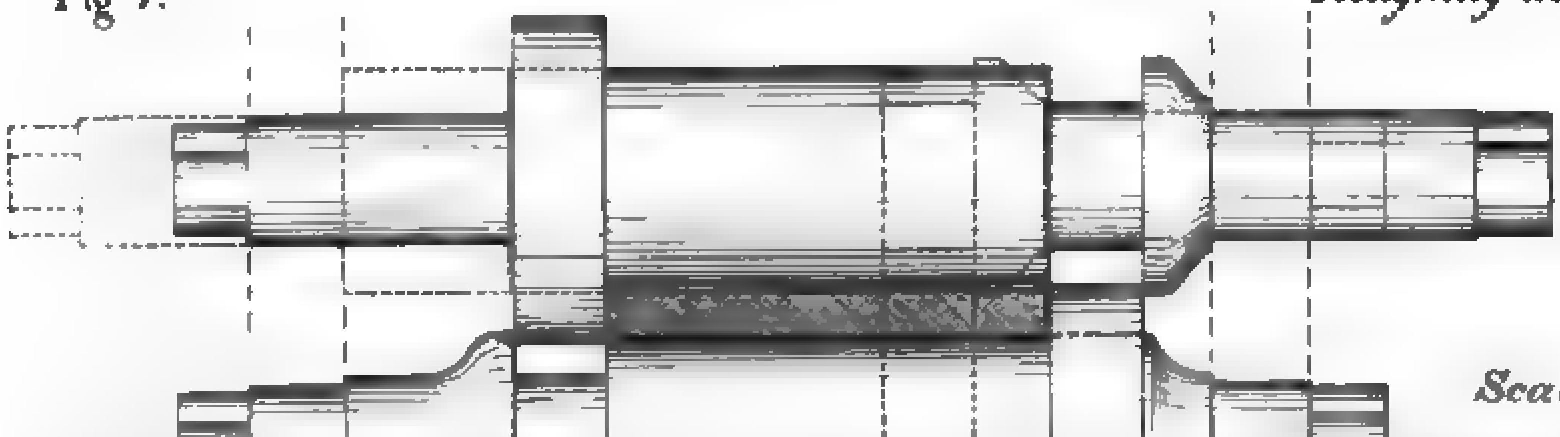
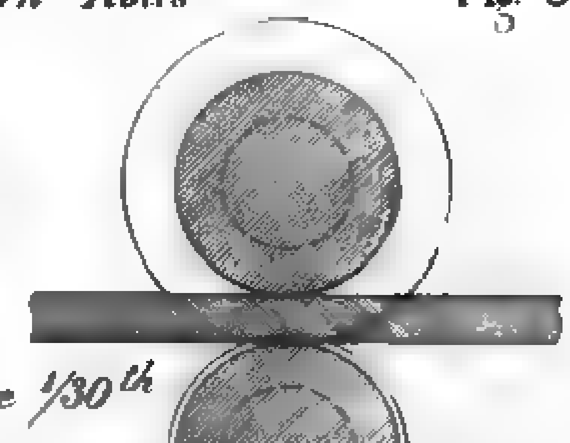


Fig. 8.



Scale 1/30th

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet

(Proceedings Inst. M. E. 1880).

CAST-STEEL INGOTS.

Plate 7.

Fig. 1. Longitudinal Section of Cylindrical Ingot.

Fig. 2. Acicular structure. Full-size.

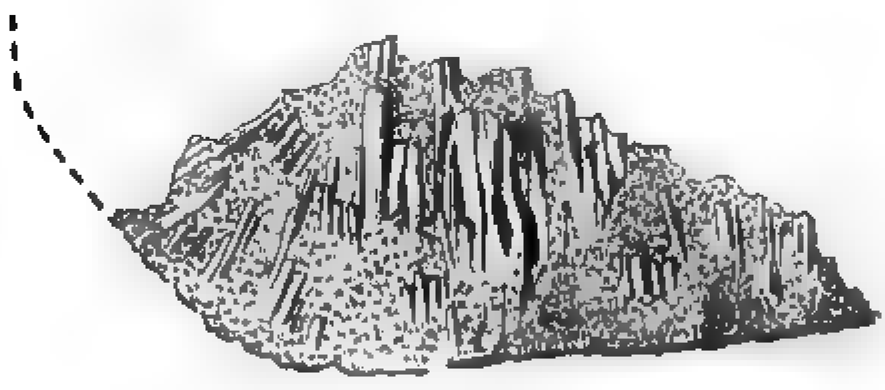


Fig. 3. Granular structure.
Two-thirds full size.

[redacted]

AST – STEEL INGOTS. *Plate 8.*

Modes of formation of Bubbles

Fig. 5.

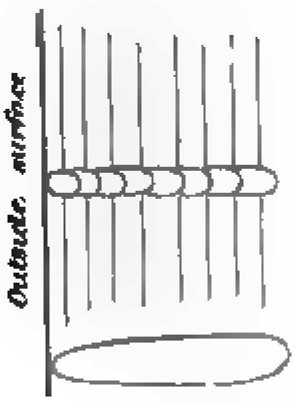
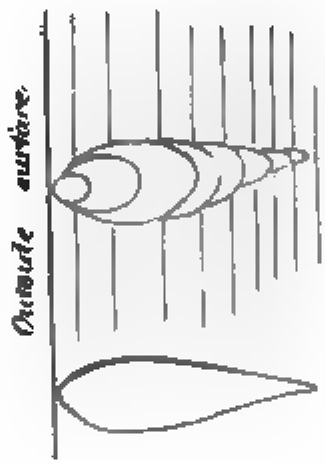


Fig. 6



. *Scale 1/8th*

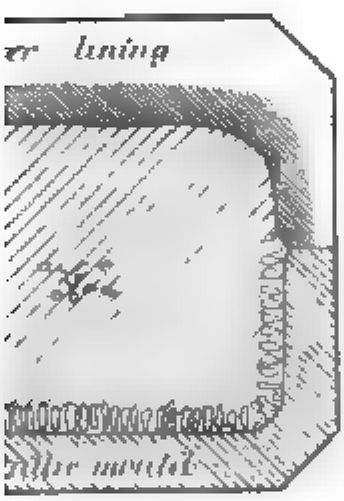
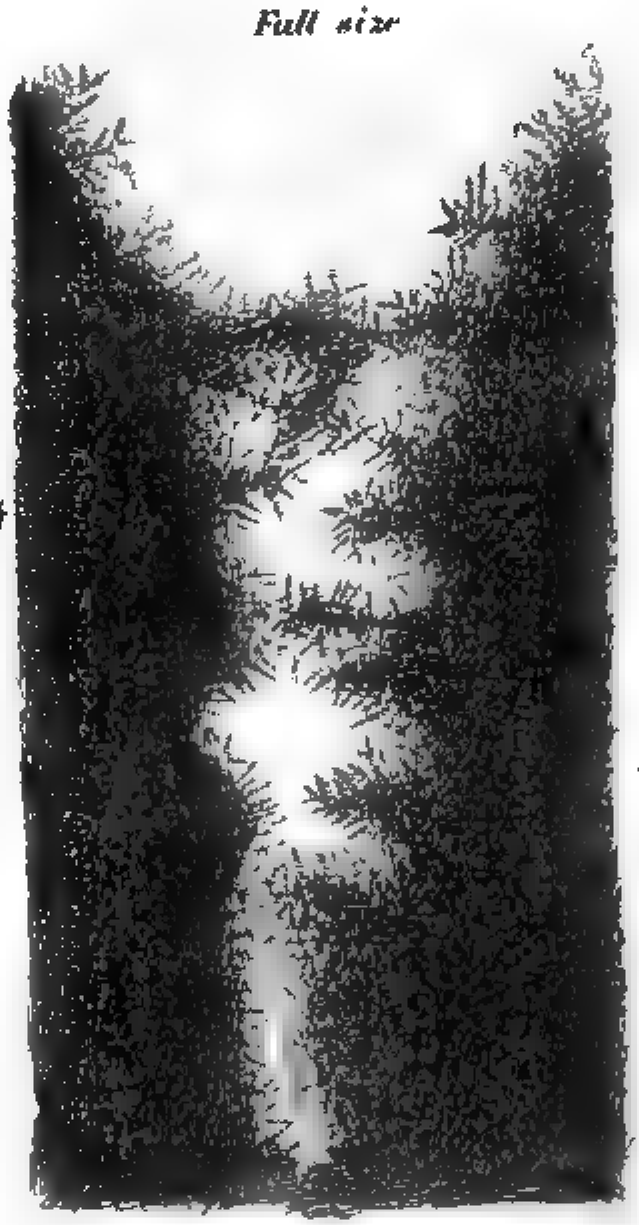


Fig. 8

Fig. 12 *Central Cavity in top of Ingot. Full size*



ST- STEEL INGOTS. *Plate 9.*

ton Ingot of Compressed Steel

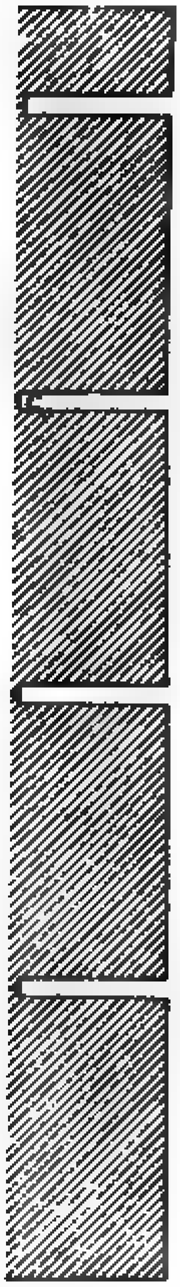
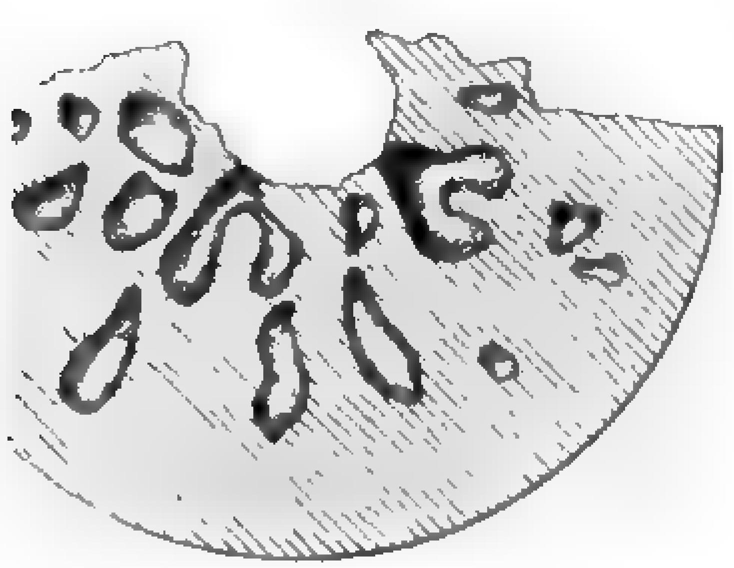


Fig. 10.
Enlargement of a. b. c.

th

Scale 1/3rd

Section at b c Scale 1/2



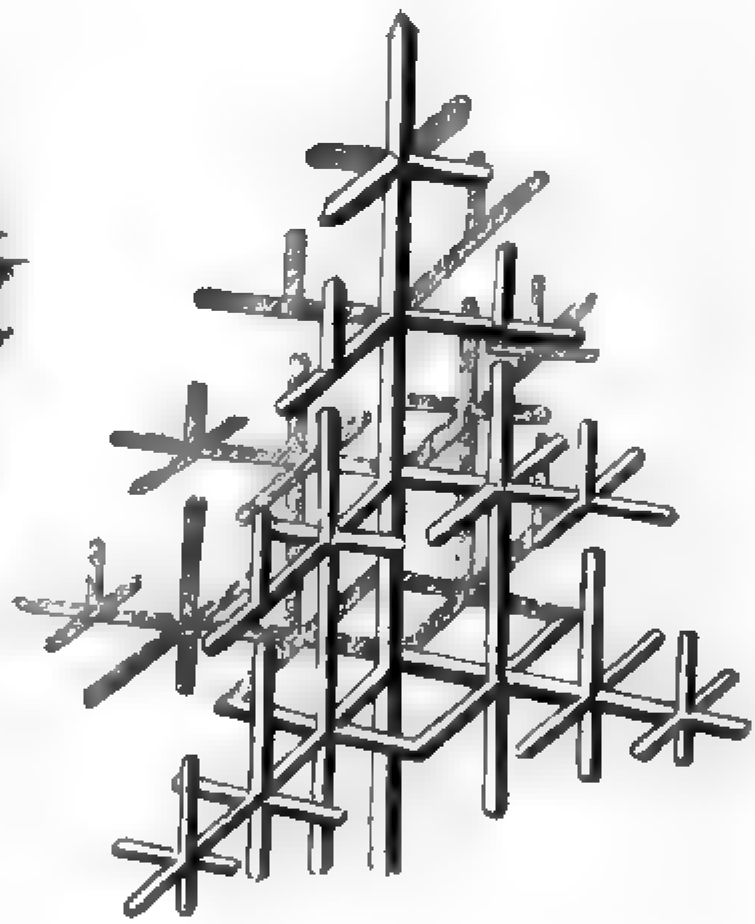
1880.)

CAST – STEEL INGOTS. *Plate 10.*

ig. 13.
ls from cavity
op of Ingot.

Scale 4 to 1.

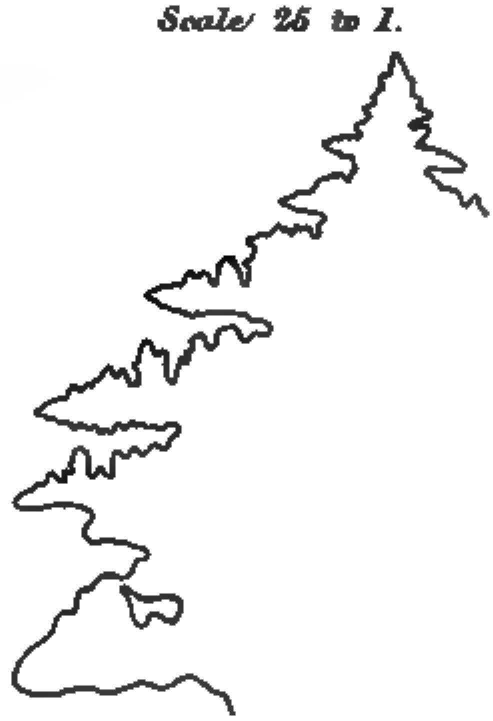
Fig 14.
Skeleton Octahedral Crystal.



Scale about 300 to 1.

i. *Twin Crystals*
n Steel Ingot.
ale 70 to 1.

Fig. 16. *Outline of Crystal.*
Scale 25 to 1.



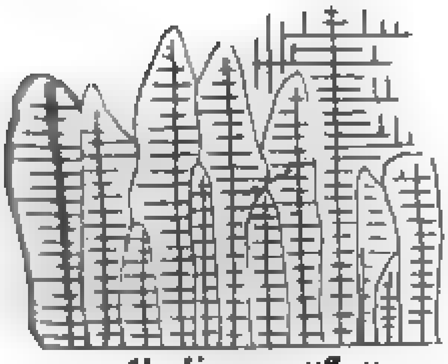
ge Inst. M.E. 1880.)

CAST-STEEL INGOTS

Plate II

Direction of growth of Crystals

Fig. 17.



Cooling surface

Fig. 18.

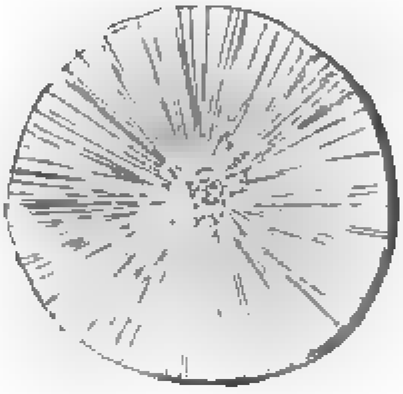


Fig. 19

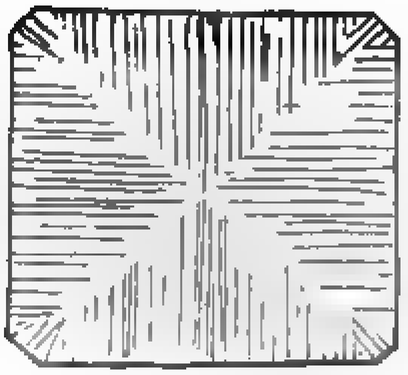
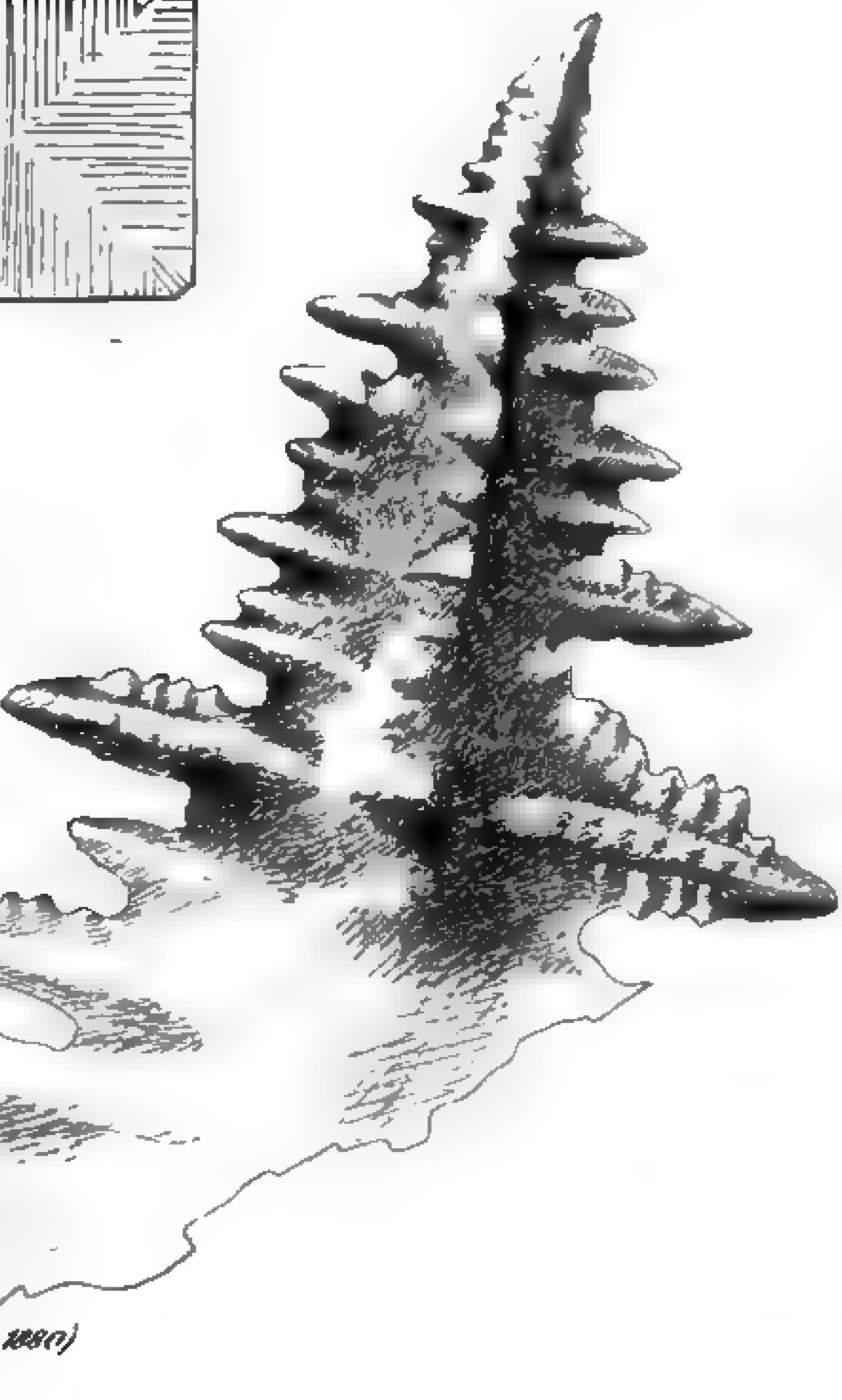


Fig. 20. *Crystal from Grey Cast Iron Scale 140 to 1.*



[redacted]

CAST – STEEL INGOTS. *Plate 13.*

Fig. 26. Fracture of Granulated Ingot.
Two thirds full size.

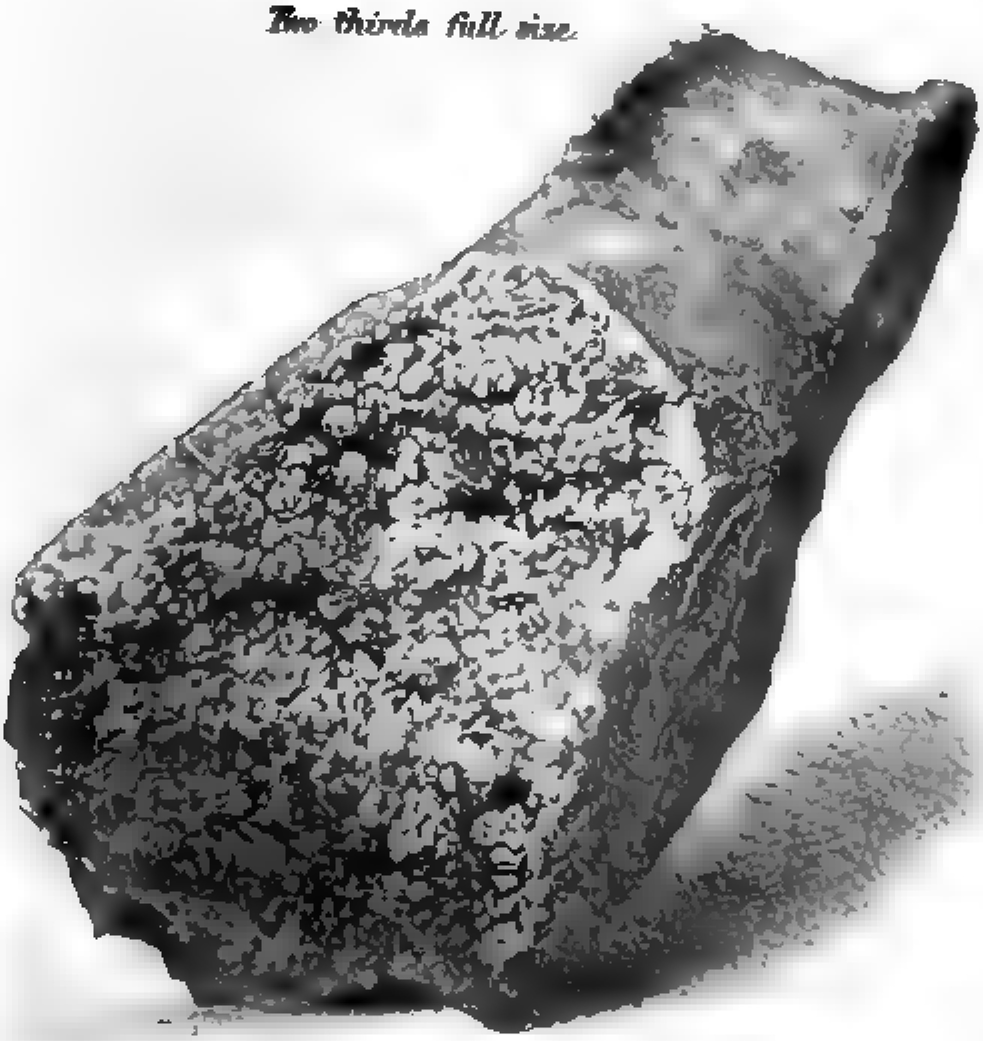
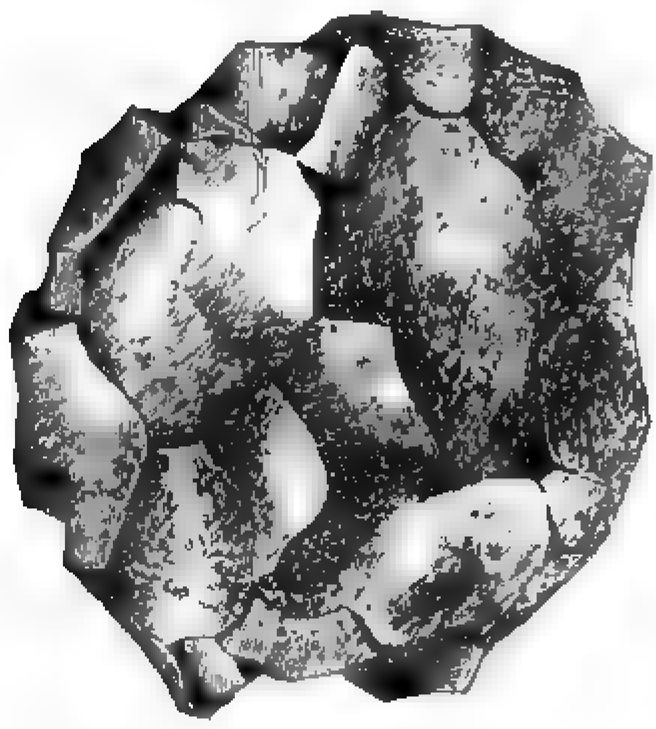


Fig. 27. Grain from Fig. 26.
Scale 7 to 1



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CAST- STEEL INGOTS. *Plate 14.*

Fig. 29.

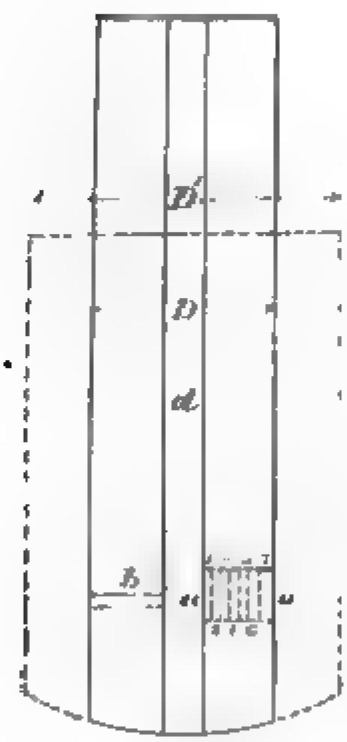
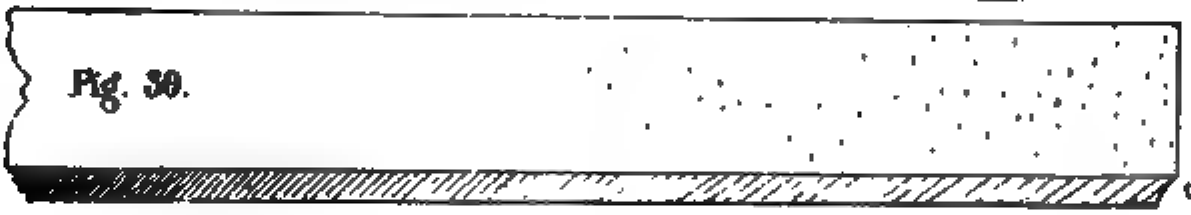


Fig. 34.

Scale 80 to 1.

Fig. 30.



Strips cut at b, Fig. 29. Half full size.

Fig. 31.

Bore of Gun

Magnified Sections of Bubbles

Fig 32

Fig 33.

(Proceedings Inst. M.E. 1880)

CAST-STEEL INGOTS. *Plate 14.*

Fig. 29.

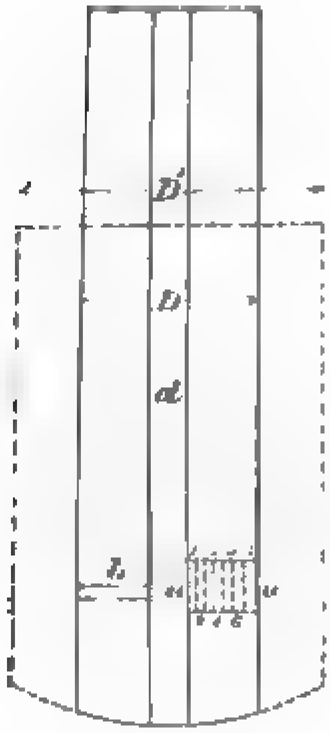


Fig. 34.

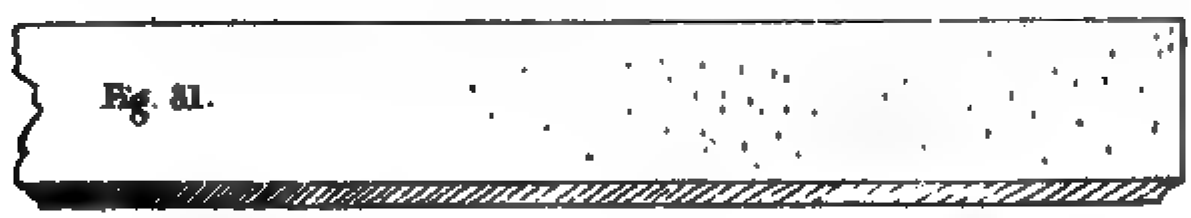
Scale 80 to 1.

Fig. 30.

Strips cut at b, Fig. 29. Half full size.

Bore of Gun

Fig. 31.



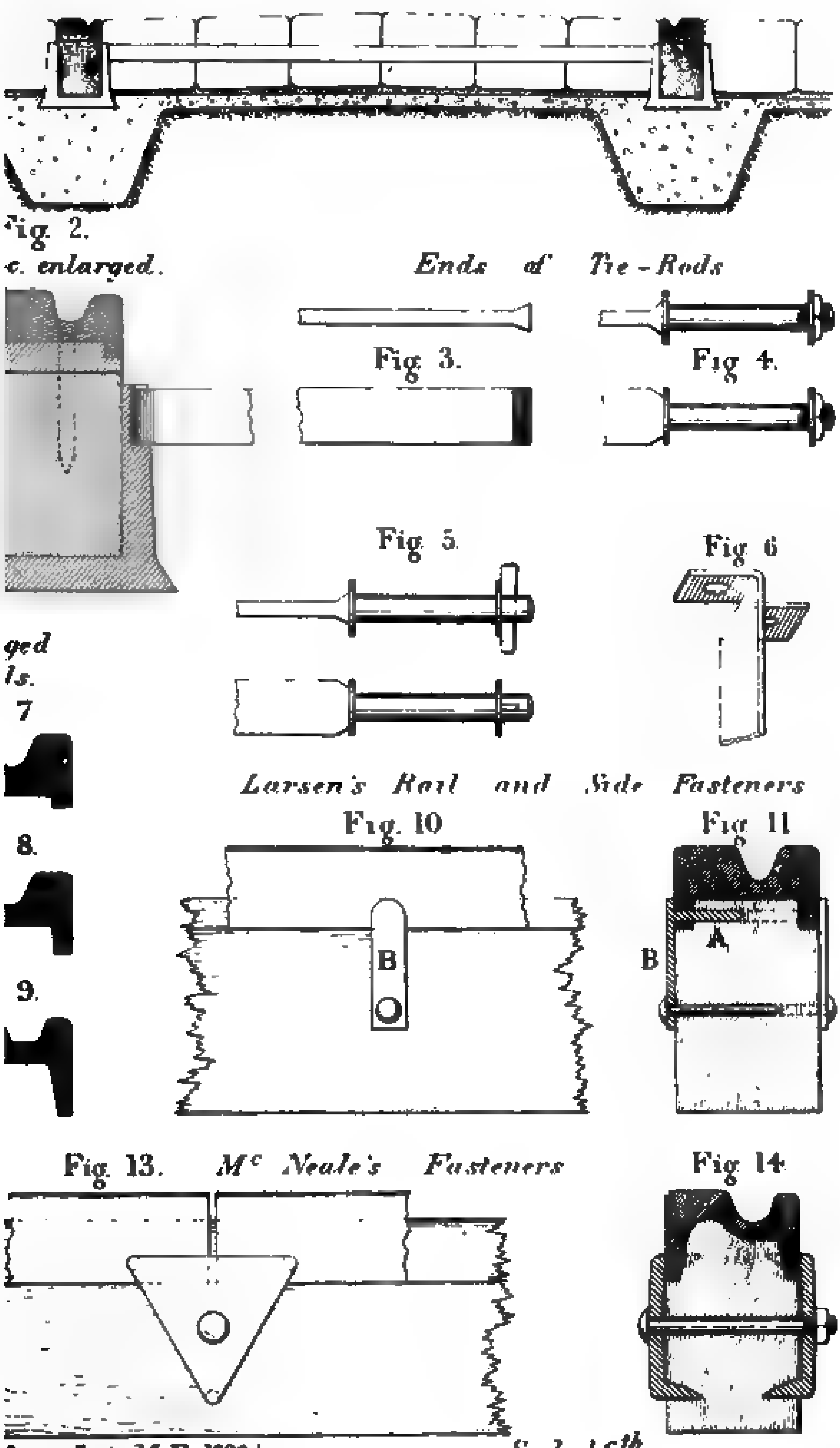
Magnified Sections of Bubbles.

Fig 32.

Fig 33.

(Proceedings Inst. M.E. 1880)

g. 1. *First London Tramway.* *Scale 1/20th*



...dings Inst. M. E. 1880.) *Scale 1/6th*

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STREET TRAMWAYS. *Plate 16.*

Fig. 12. *Scale 1/8th*

Screw Cramp.

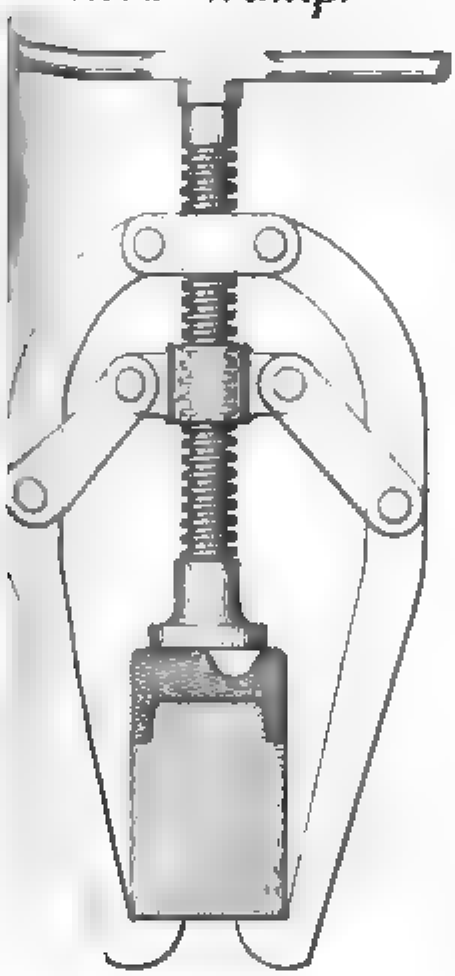
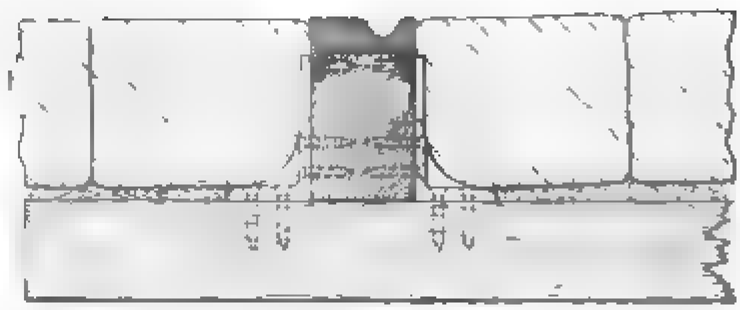


Fig. 15. *Scale 1/12th*

Pimlico & Greenwich Tramway.



Paris Tramway Rails.

Fig. 16. *Scale 1/6th*

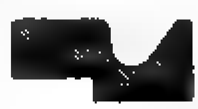


Fig. 17.

Larsen's System.

Scale 1/6th

Fig. 18.

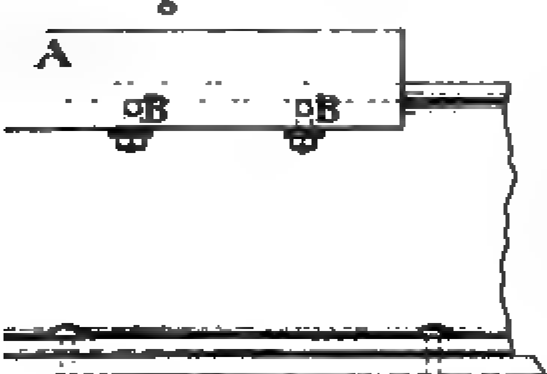


Fig. 19.

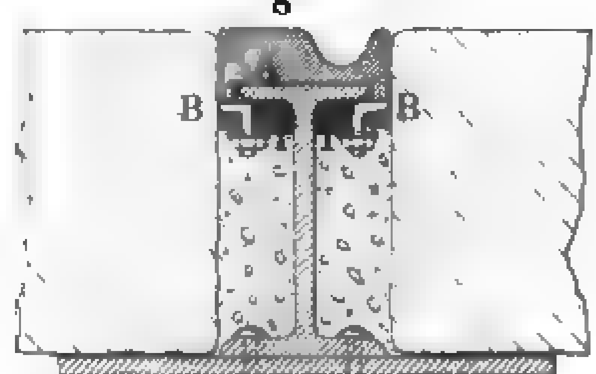


Fig. 20.

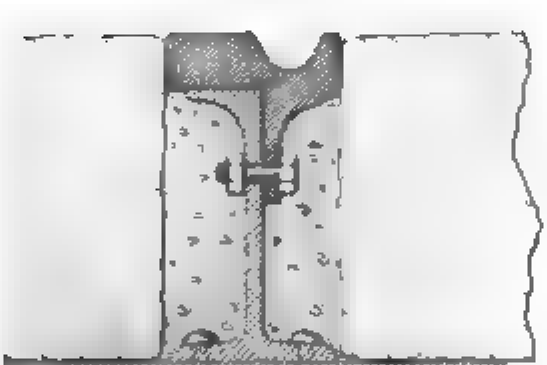
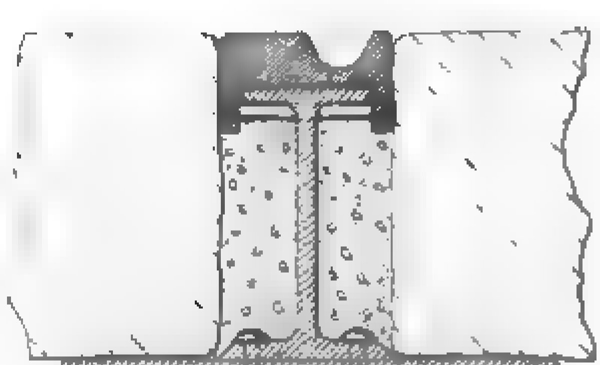


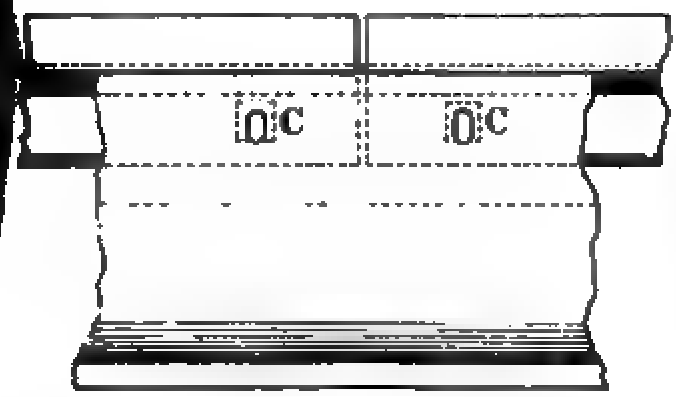
Fig. 21.



[redacted]

STREET TRAMWAYS. *Plate 17.*

Fig. 22. *Barker's System* Fig. 23



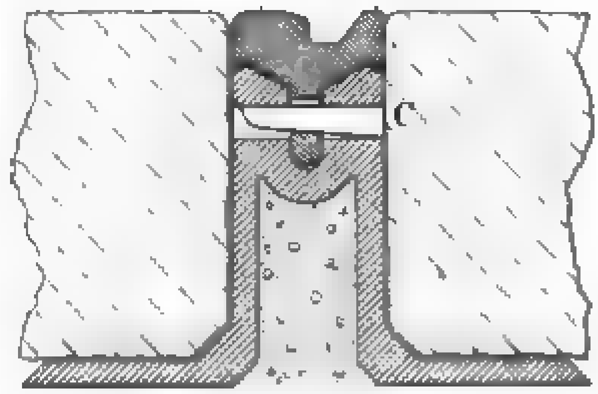
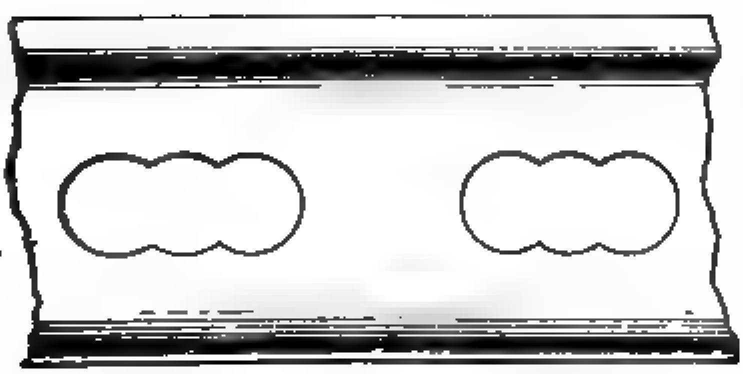


Fig. 24. *Gowan's System* Fig. 25.



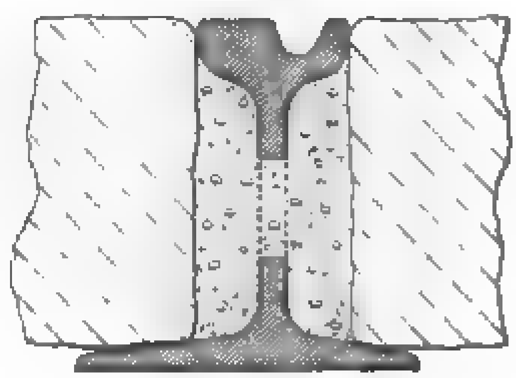
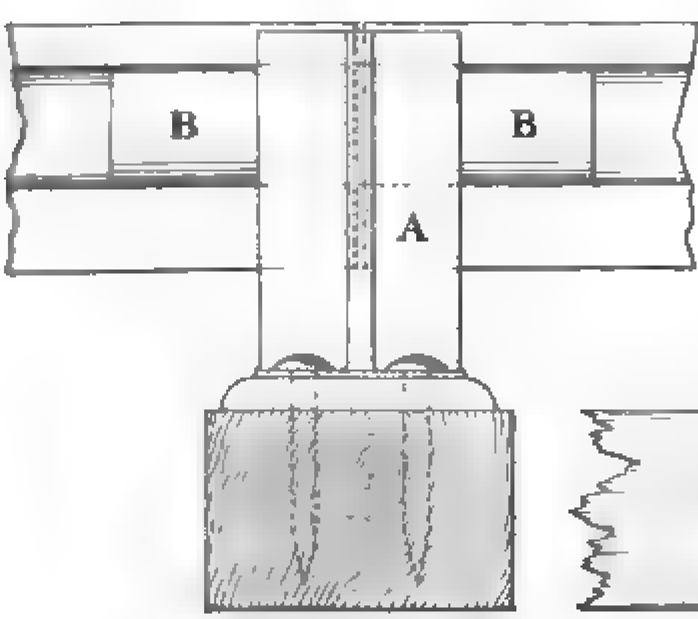
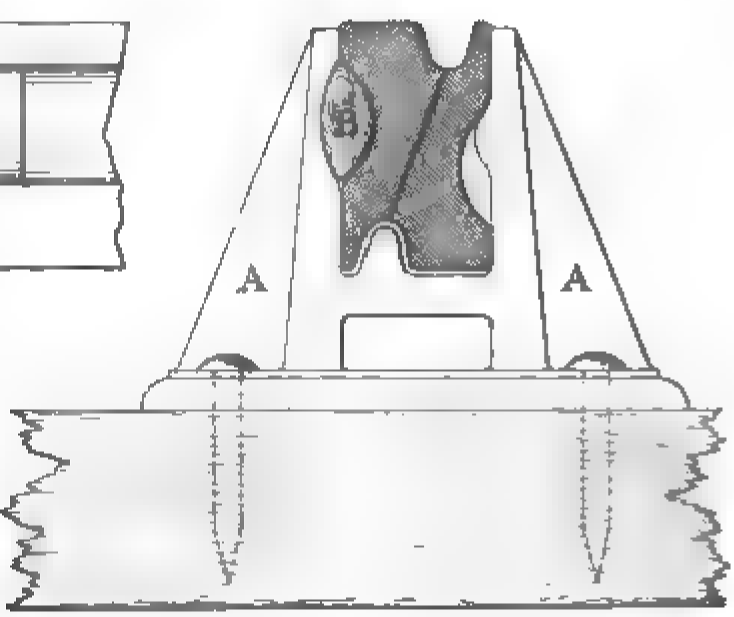


Fig. 26. *Aldred's System* Fig. 27.





(Proceedings Inst. M. E. 1880) *Scale 1/6th*

STREET TRAMWAYS. *Plate 18.*

Fig. 28. *Winby's System.* Fig. 29.

Scale 1/6 th

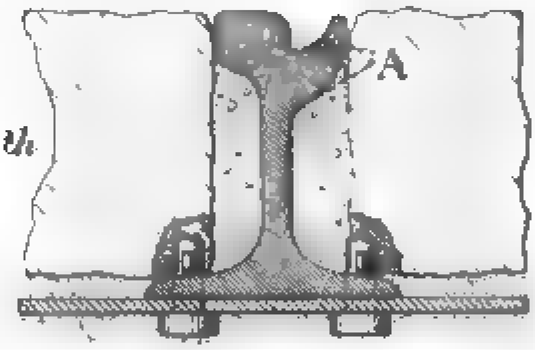
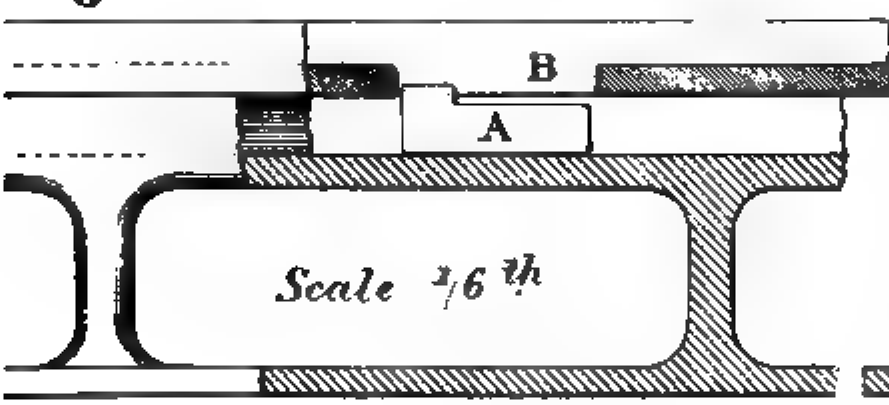
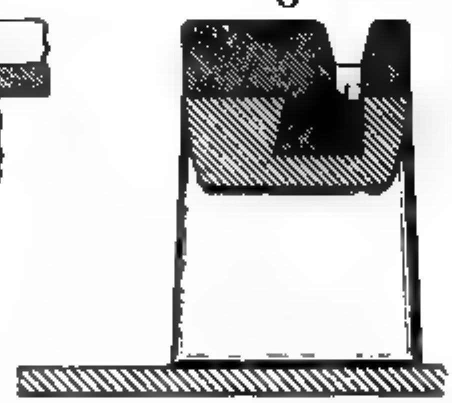
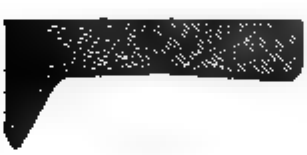


Fig. 31. *Mackisson's System.* Fig. 32.





ig. 30. *Wheel-lange (worn.)*



Reversible Rails.

Fig. 33. Fig. 34.

Scale 1/6 th

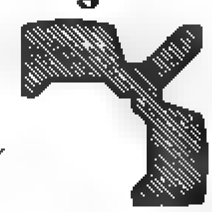


Fig. 35. *Quayside Tramway, Glasgow*

Scale 1/24 th

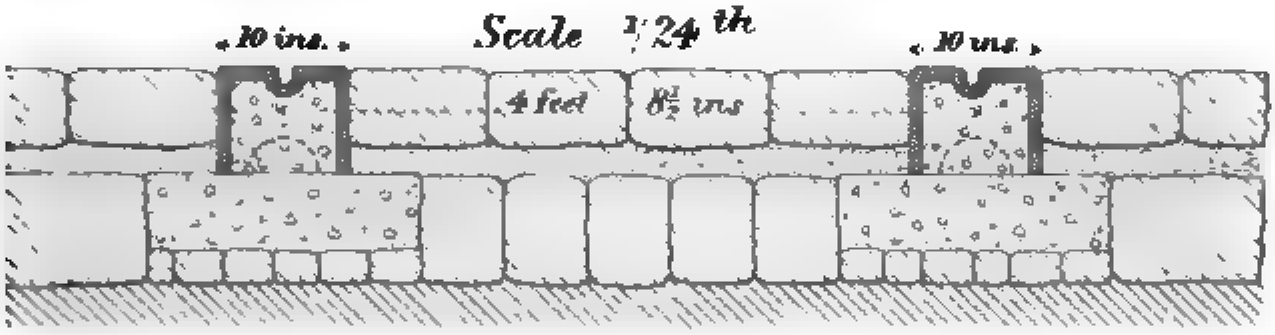
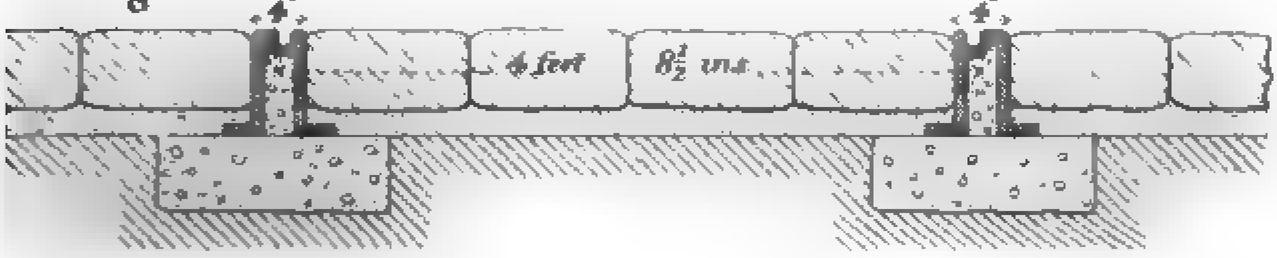


Fig. 36.



Arrangement for draining dip-workings, Griff Colliery.

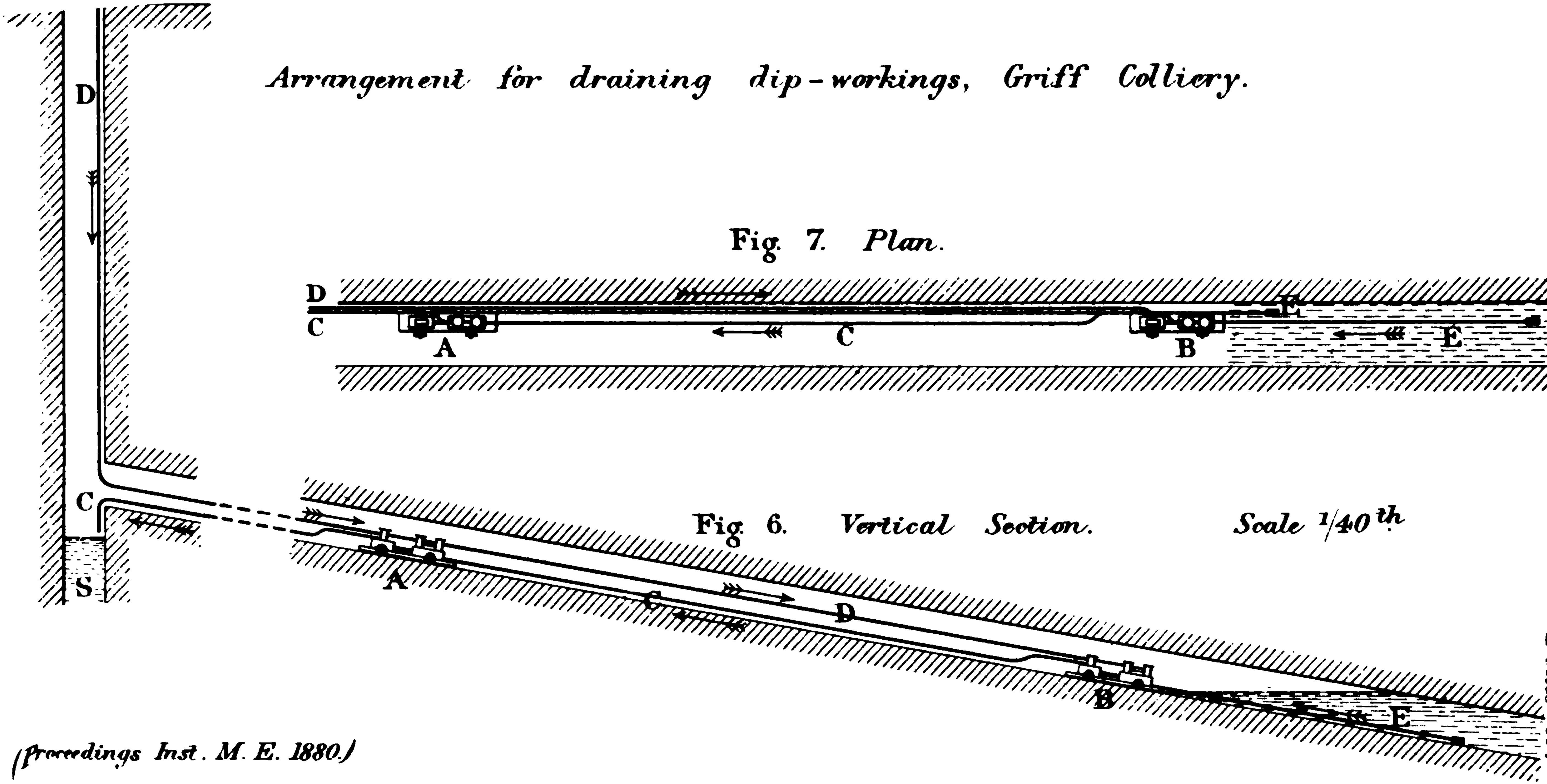


Fig. 7. Plan.

Fig. 6. Vertical Section. Scale 1/40th.

Plate 20.

[redacted]

WATER-PRESSURE MINING ENGINES.

Arrangement for draining dip-workings, Griff Colliery.

Fig. 6.

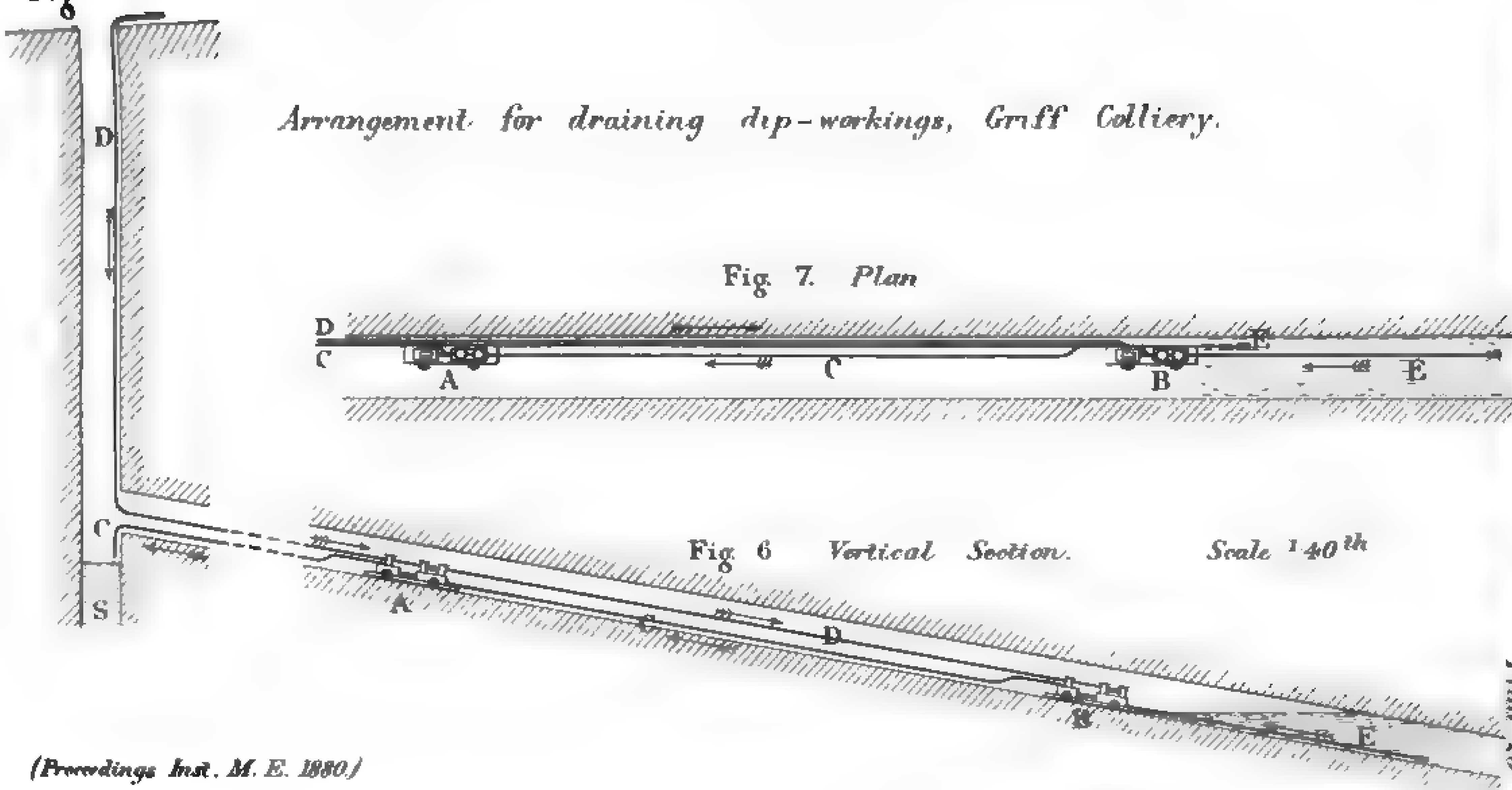


Fig. 7. *Plan*

Fig. 6 *Vertical Section.* *Scale 1/40th*

Plate 20

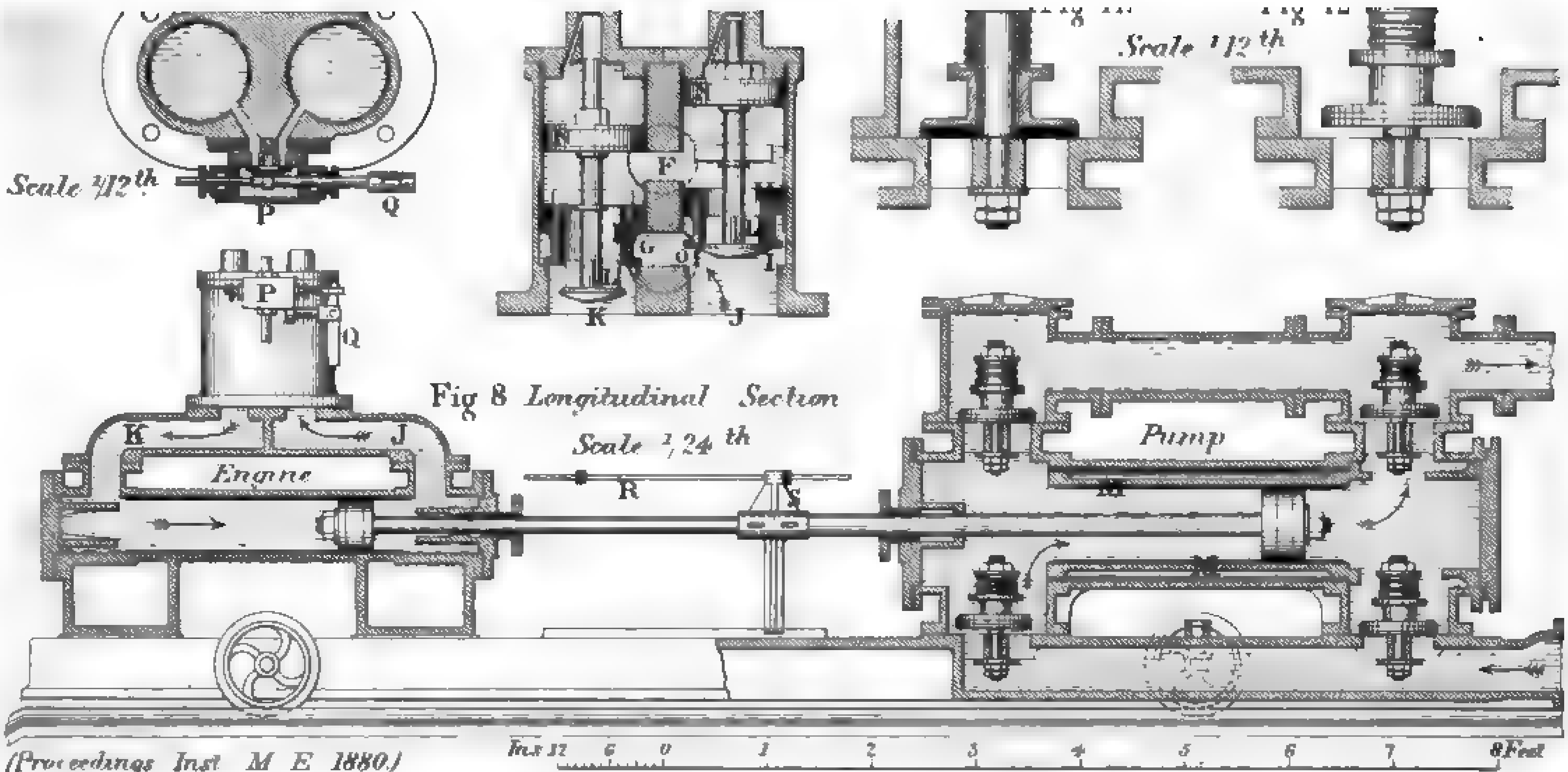
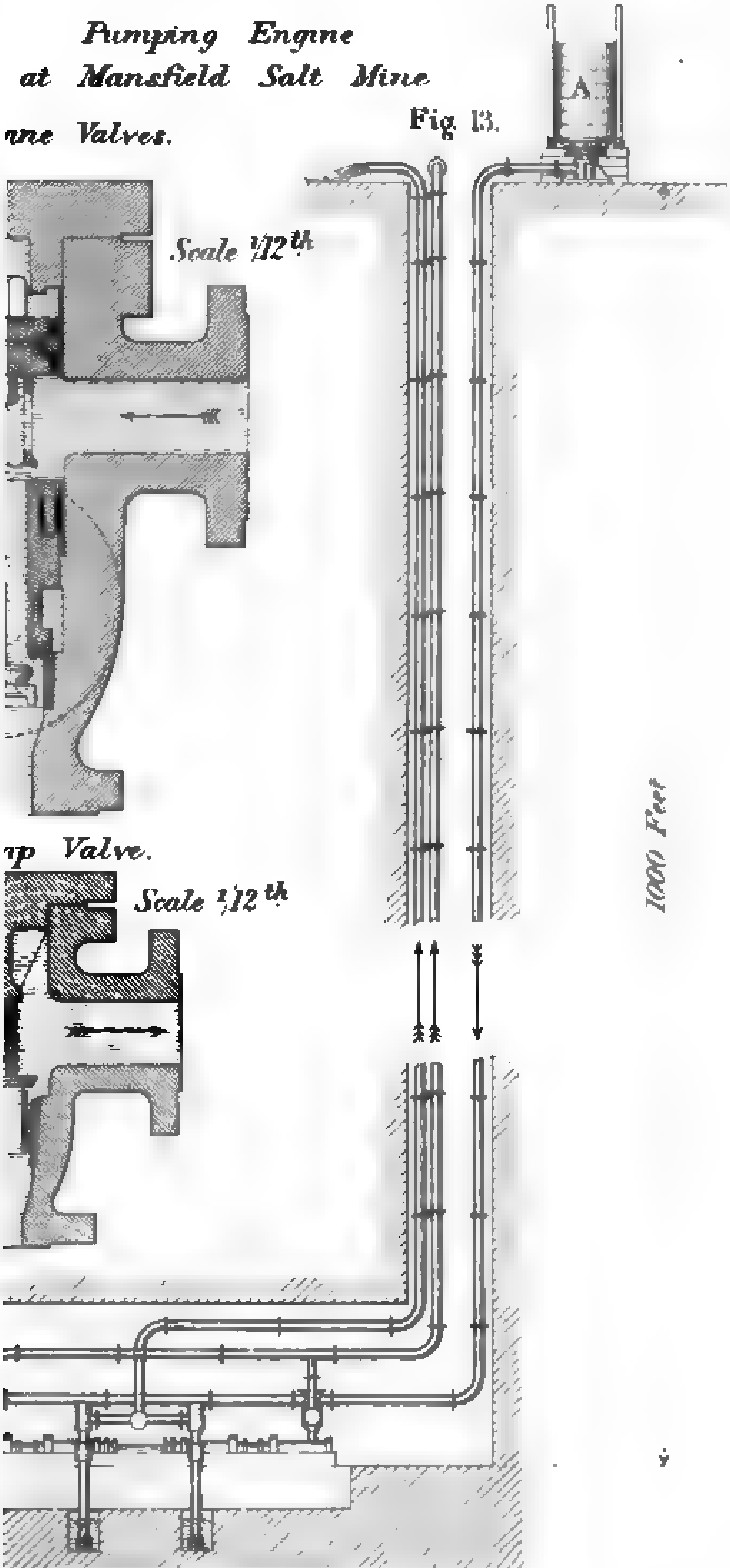

Scale 1/12th
P
Q
K
F
G
O
I
J
N
Scale 1/12th
Fig 11
Fig 12
Fig 8 Longitudinal Section
Scale 1/24th
Engine
Pump
R
S
Ins 12 6 0 1 2 3 4 5 6 7 8 Feet
(Proceedings Inst M E 1880)

Plate 21

R-PRESSURE MINING ENGINES. *Plate 22.*

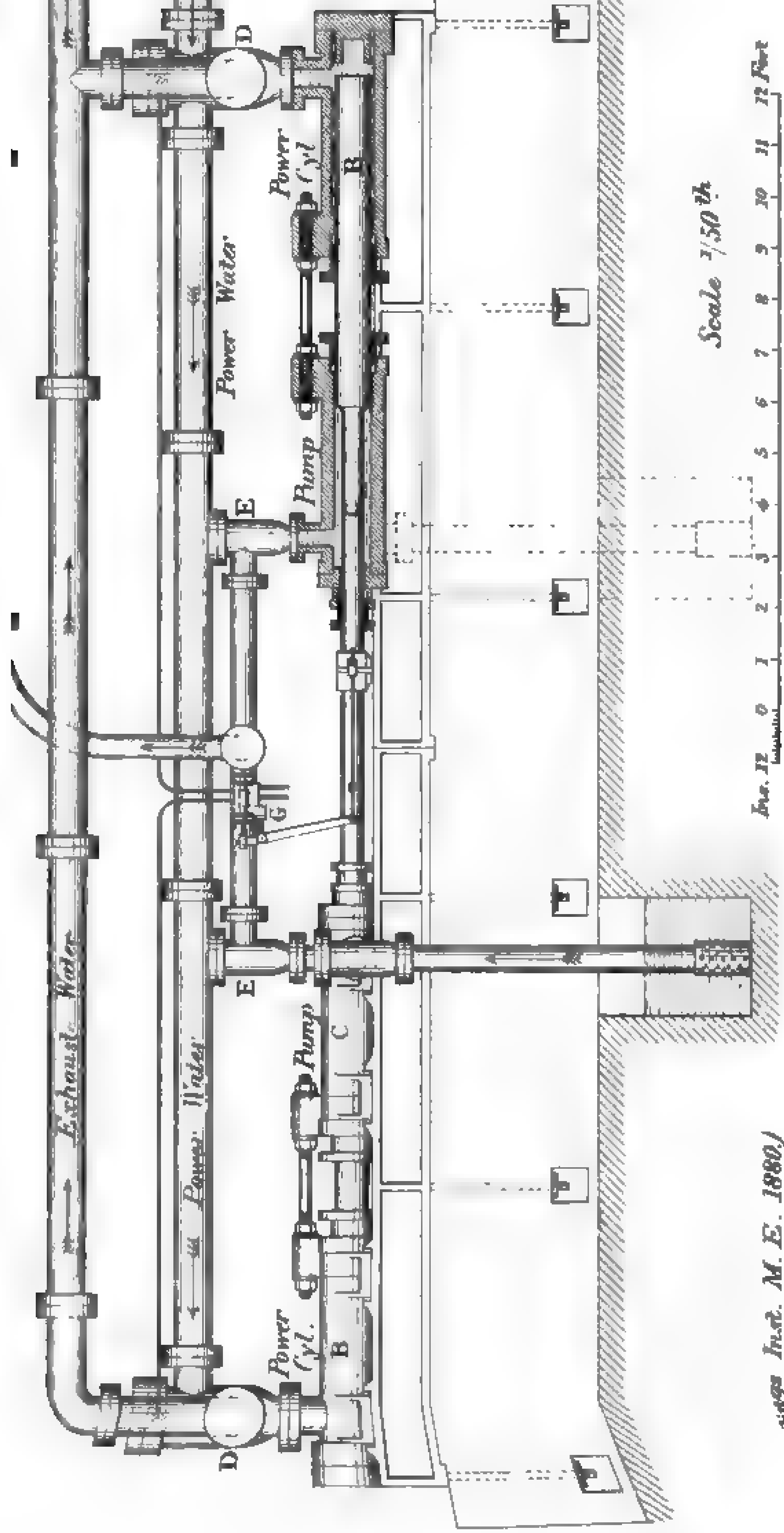
Pumping Engine at Mansfield Salt Mine



st. M. E. 1880)

Scale 1/200th

Plate 23.



(Proceedings Inst. M. E. 1880.)

[redacted]

'ATER-PRESSURE MINING ENGINES. *Plate 24*

Fig 17 *General Arrangement at A D Mine.*

Scale vertical & horizontal, 800 feet to the inch

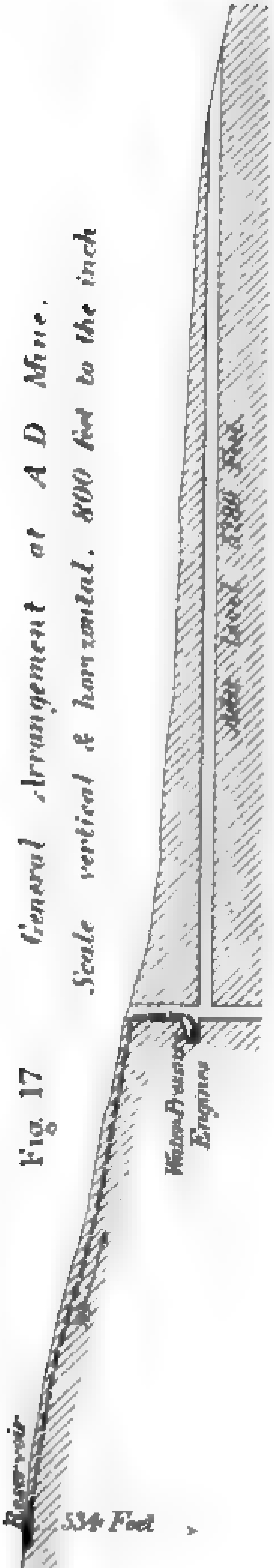


Fig 19.

Pump Bucket

Scale 1/12th

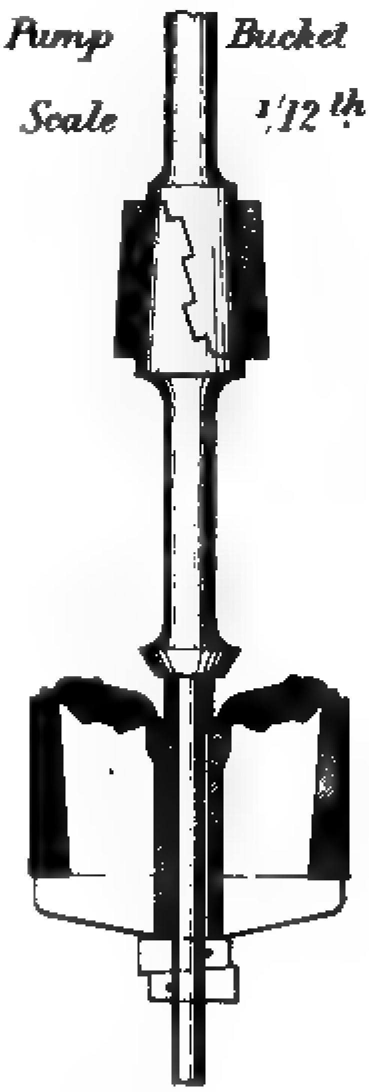
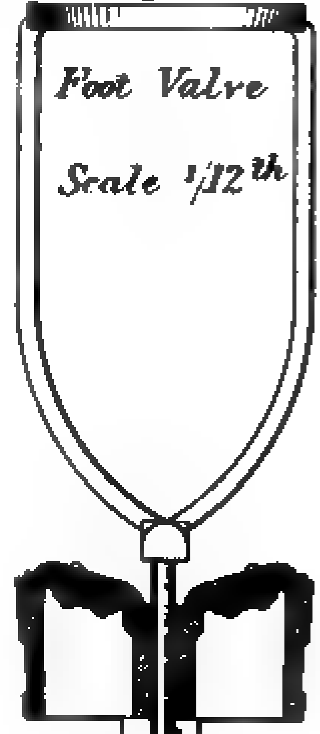


Fig. 20.



Pumping Engine A D Mine

Fig. 18. *Scale 1/20th*

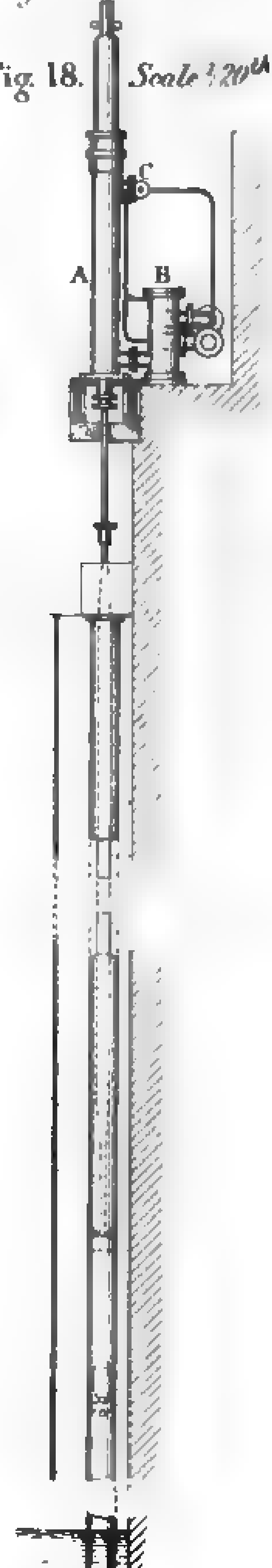
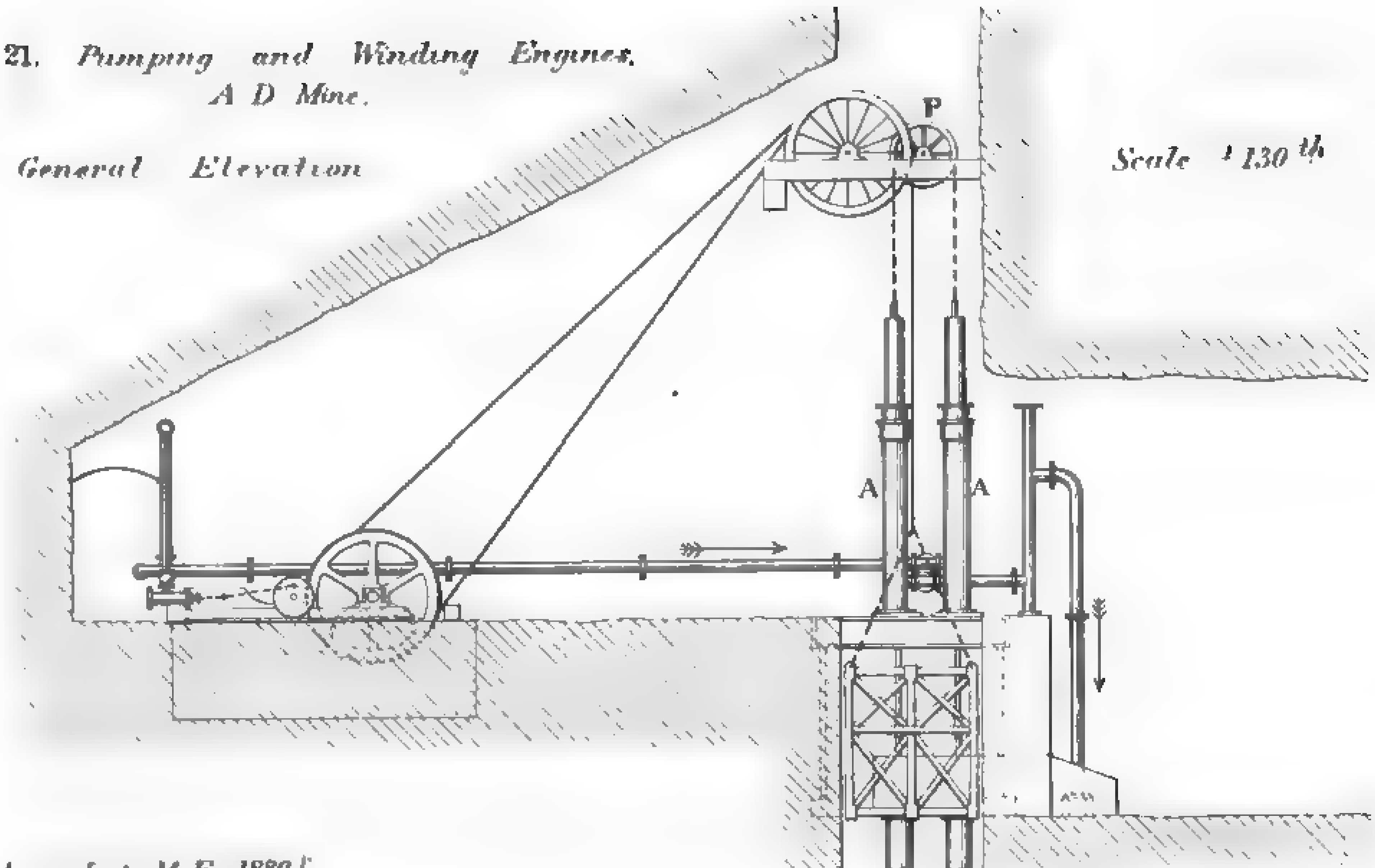


Fig. 21. *Pumping and Winding Engines, A D Mine.*

General Elevation

Scale 1/130th



(Proceedings Inst. M. E. 1880.)

Pumping Engine at A D Mine

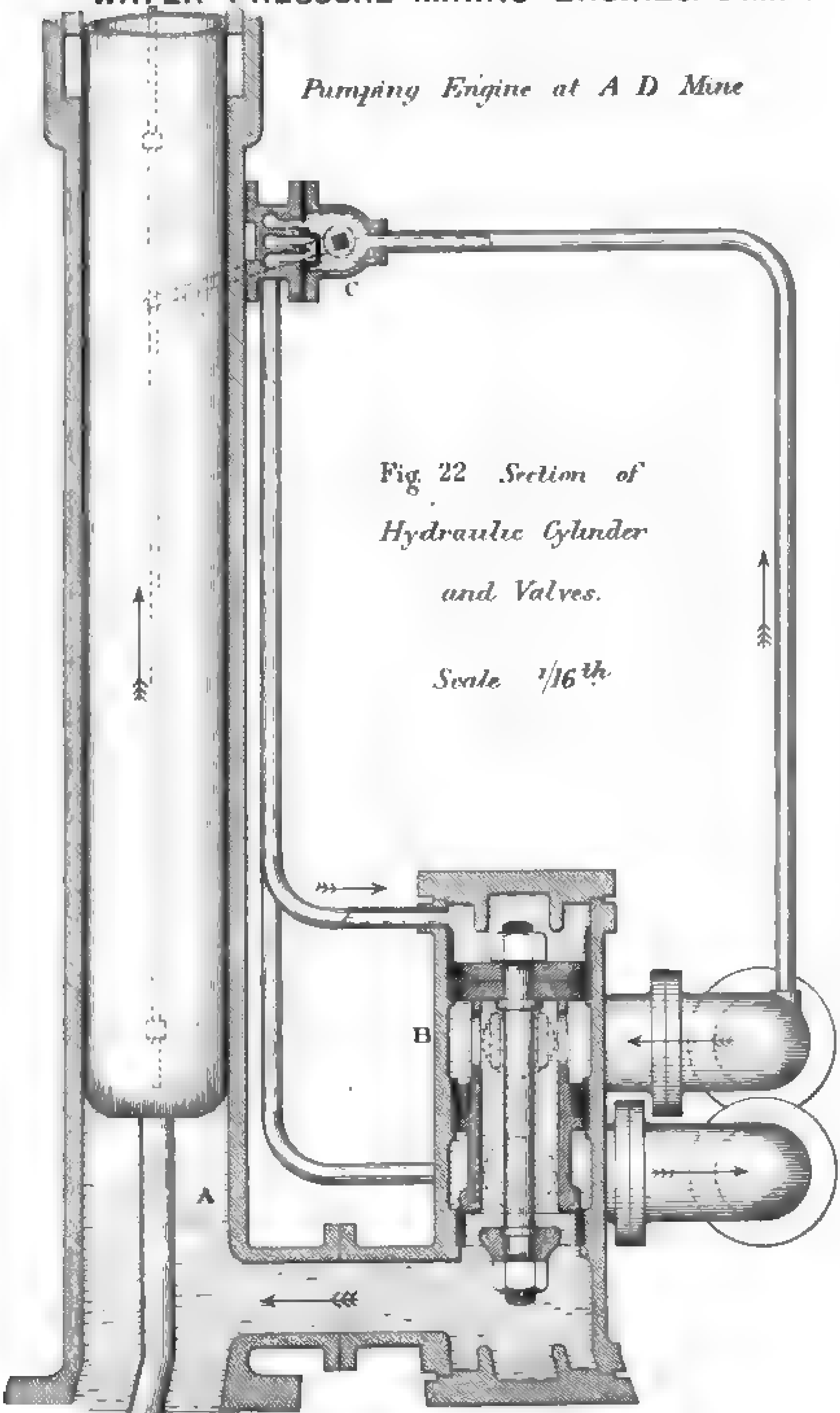


Fig. 22 *Section of Hydraulic Cylinder and Valves.*

Scale 1/16th

ATER-PRESSURE MINING ENGINES. *Plate 27.*

Winding Engine at A D Mine.

ig. 23. *Side Elevation* *Scale 1/48th.*

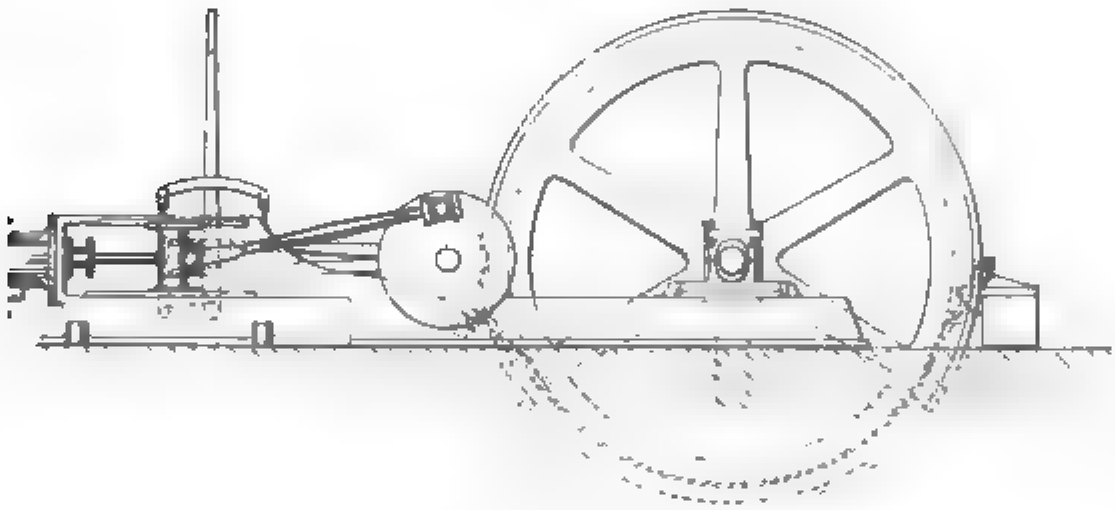
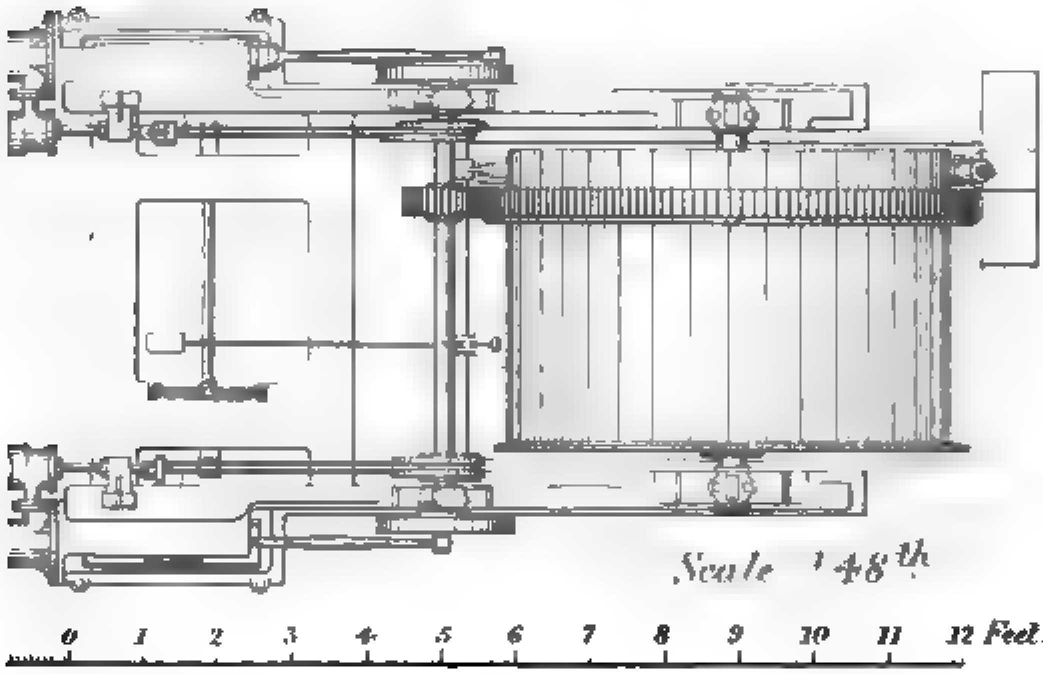
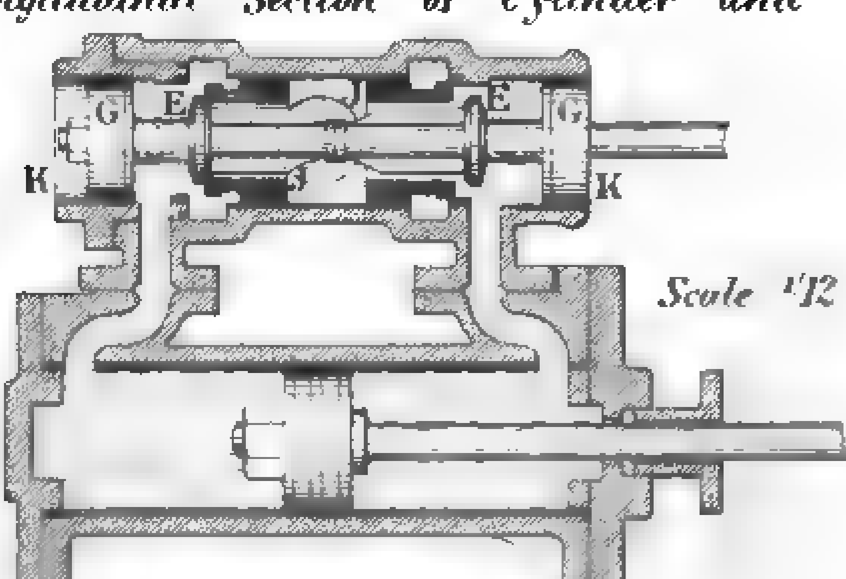


Fig. 24. *Plan.*



. *Longitudinal Section of Cylinder and Valve.*



[redacted]

WATER-PRESSURE MINING ENGINES. *Plate 28.*

Mode of dealing with Water coming into Shaft, Hutton Henry Colliery, Wingate.

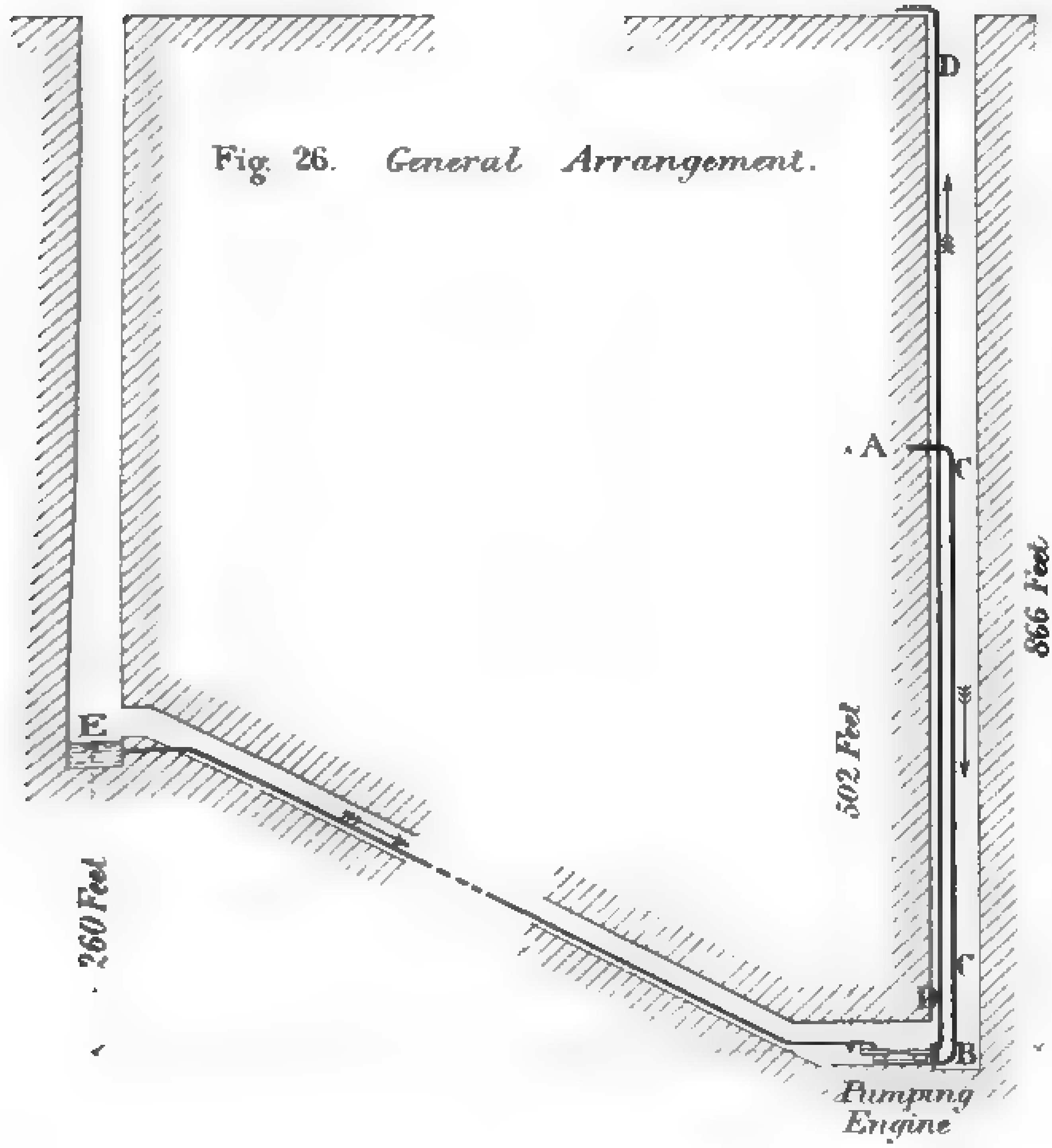
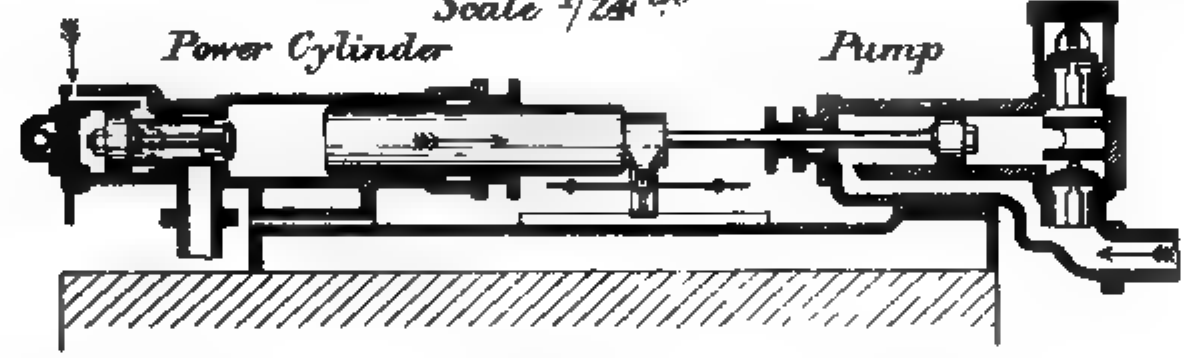


Fig. 26. *General Arrangement.*

Fig. 27. ***Longitudinal Section of Pumping Engine.***

Scale 1/24th



(Proceedings Inst. M. E. 1880.)

WATER-PRESSURE MINING ENGINES.

Sketch of Engine, using the same pipe for supply and delivery.

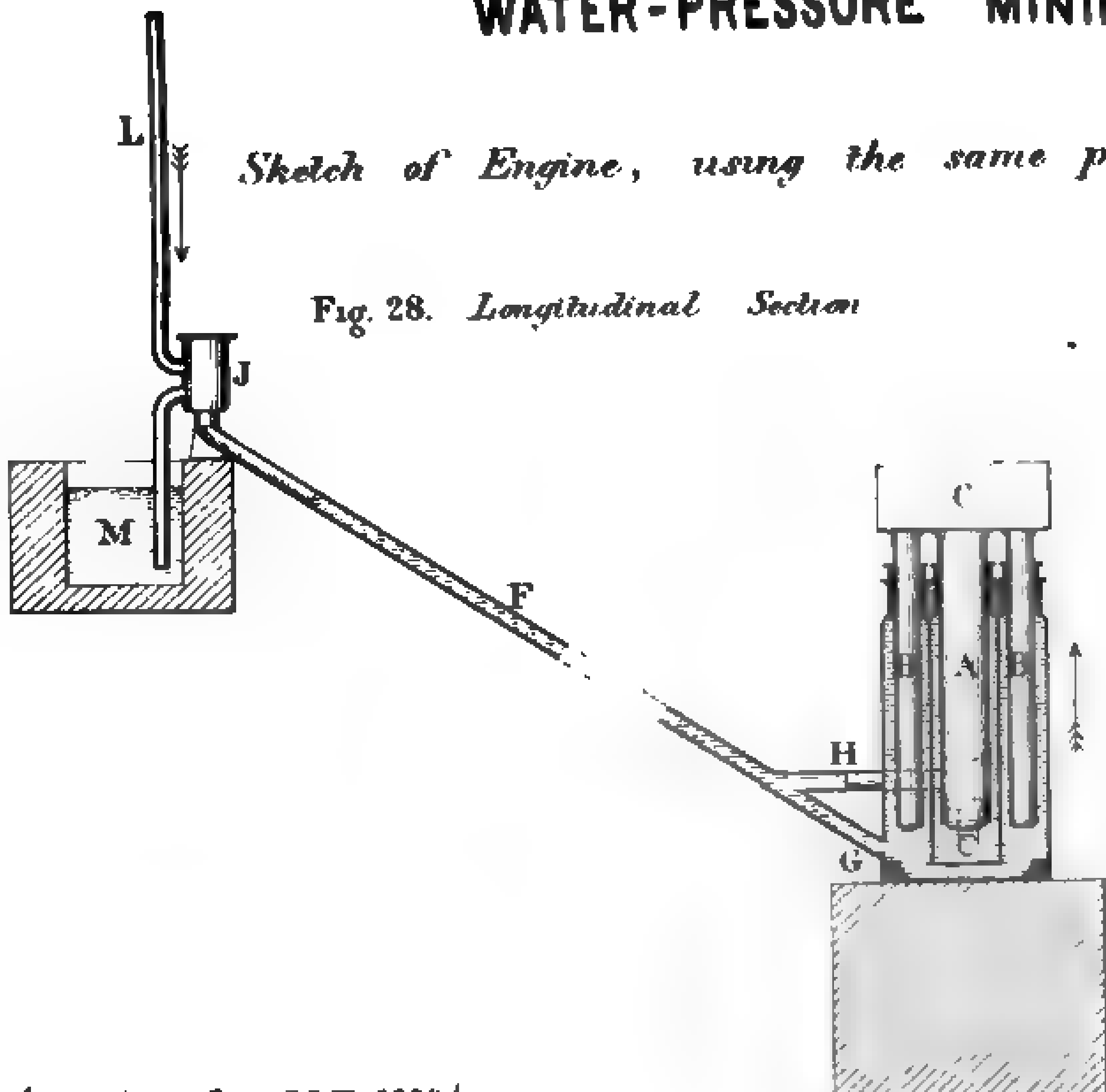


Fig. 28. *Longitudinal Section*

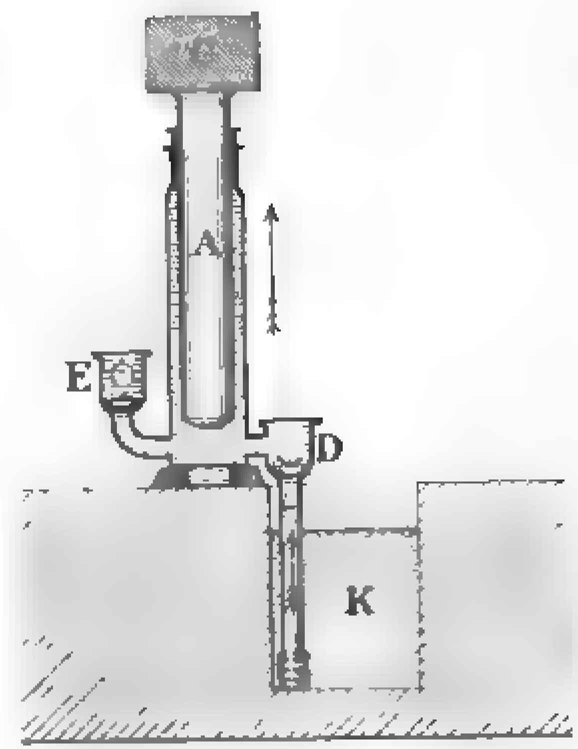


Fig 29. *Transverse Section*

Plate 29.

[illegible]
[illegible]

[redacted]

Curves of Electromotive Force and Current.

Fig 1. *Siemens Medium size machine*

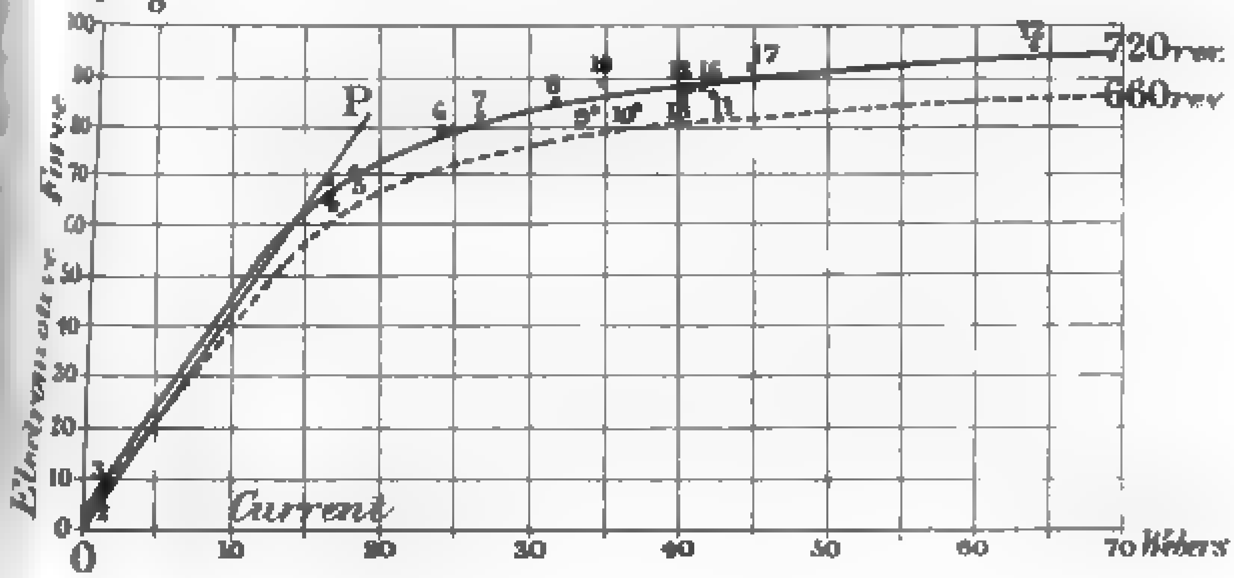


Fig. 2. *Gramme machine, curve* G.
Siemens Medium, curve Sm.
Siemens Smallest, curve Ss.

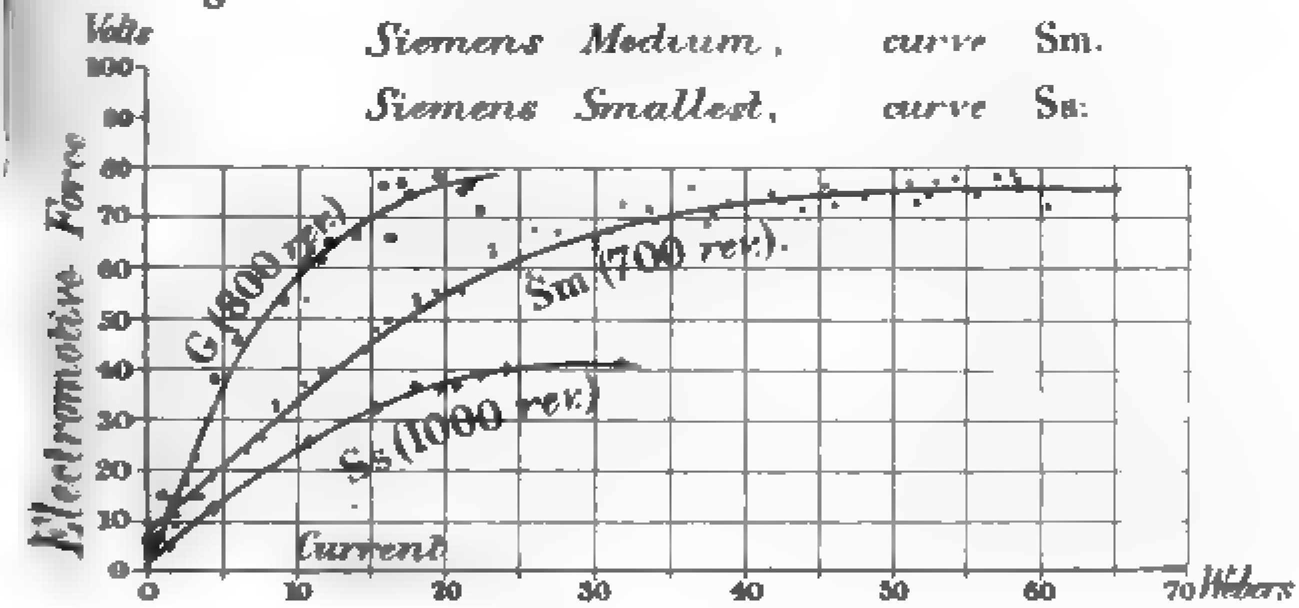
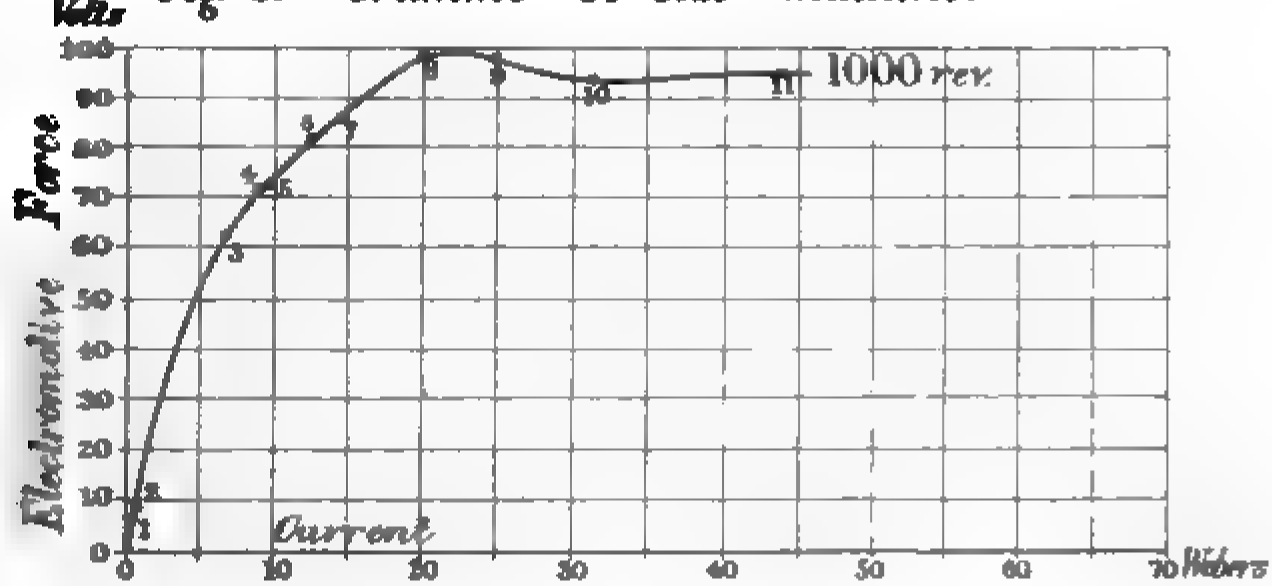


Fig. 3. *Gramme A size machine.*



(Proceedings Inst. M. E. 1880)

Plate 31

Fig. 3. *Longitudinal Section.*

Scale 1/24th

Fig. 4 *Transverse Section*

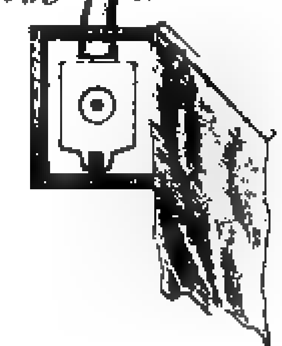


Fig. 5. *Field Piece.*
Half full size.

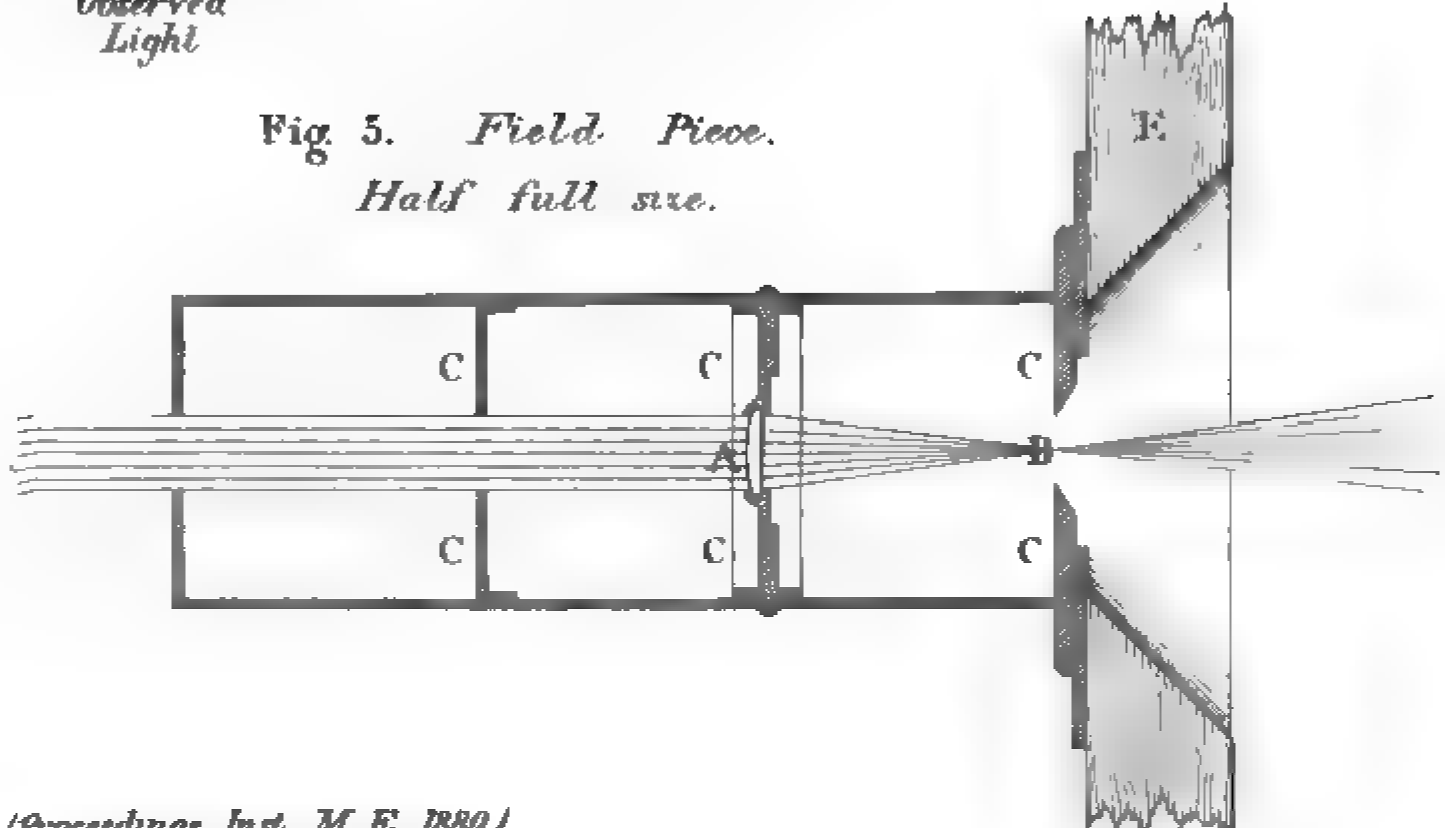


Fig. 6.

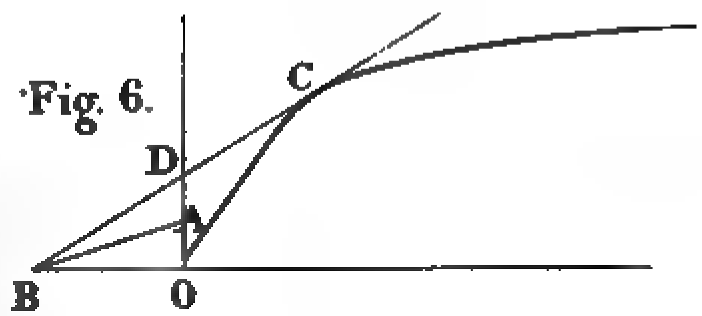
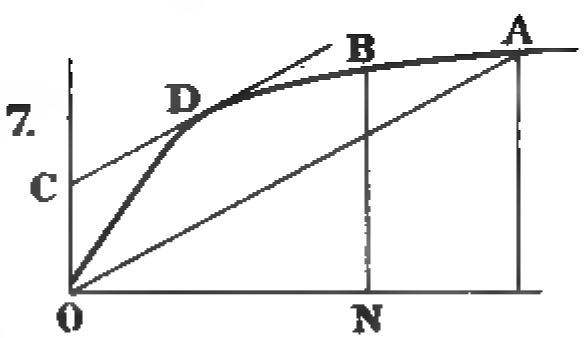


Fig. 7.

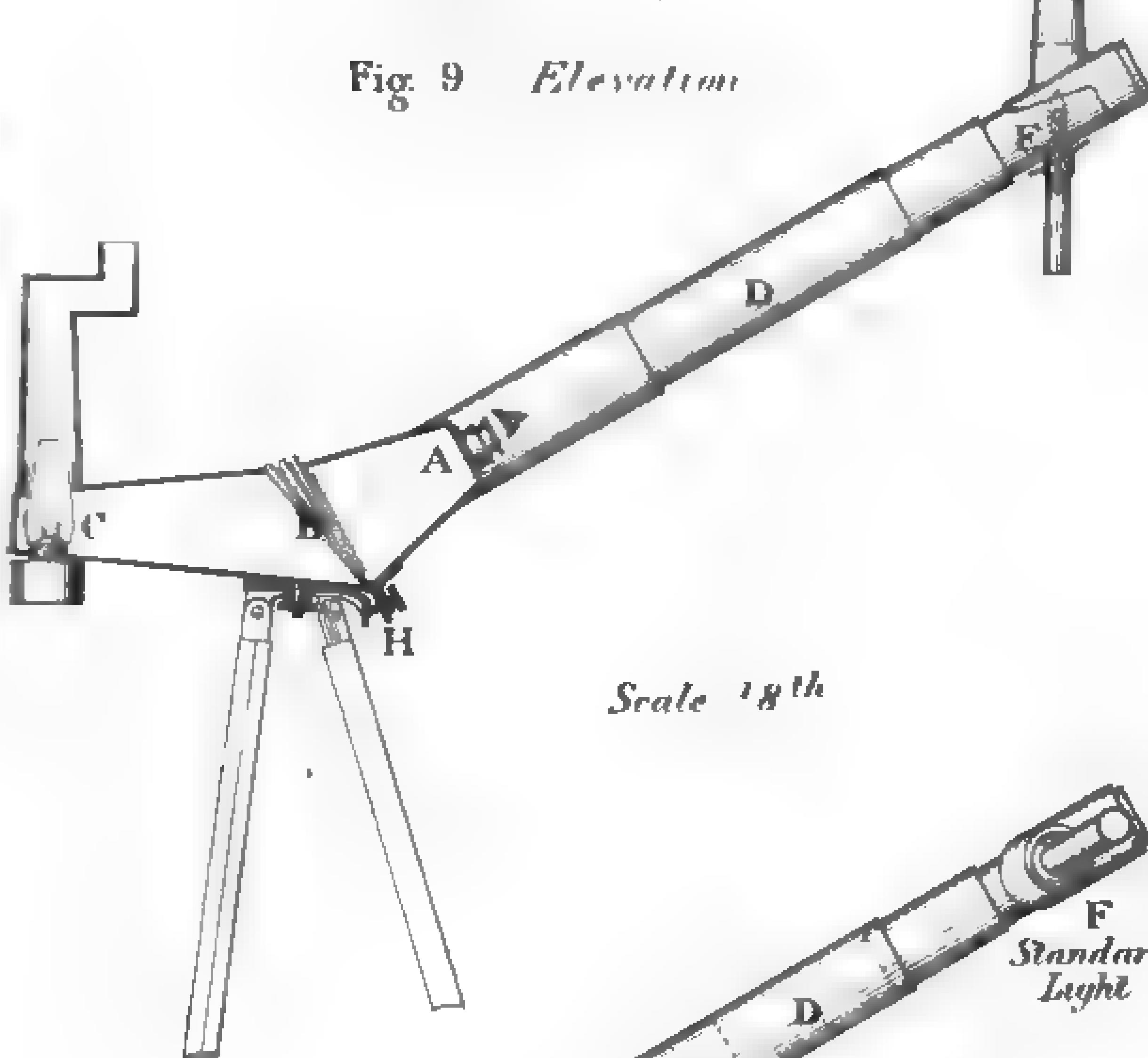


(Proceedings Inst. M. E. 1880.)

ELECTRIC LIGHTING. *Plate 32.*

Portable Photometer for Powerful Lights.

Fig. 9 *Elevation*



Scale 1/8th

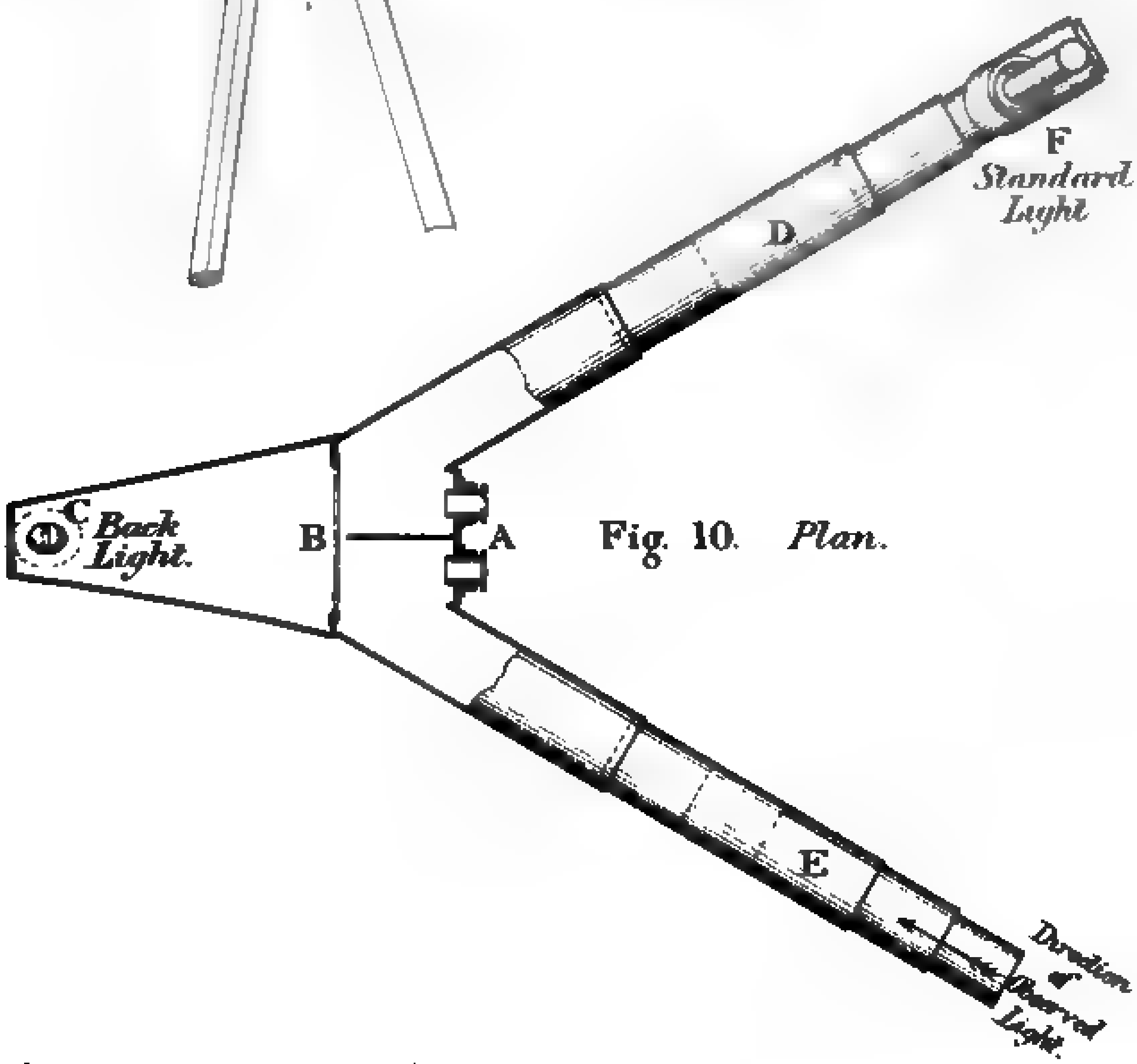
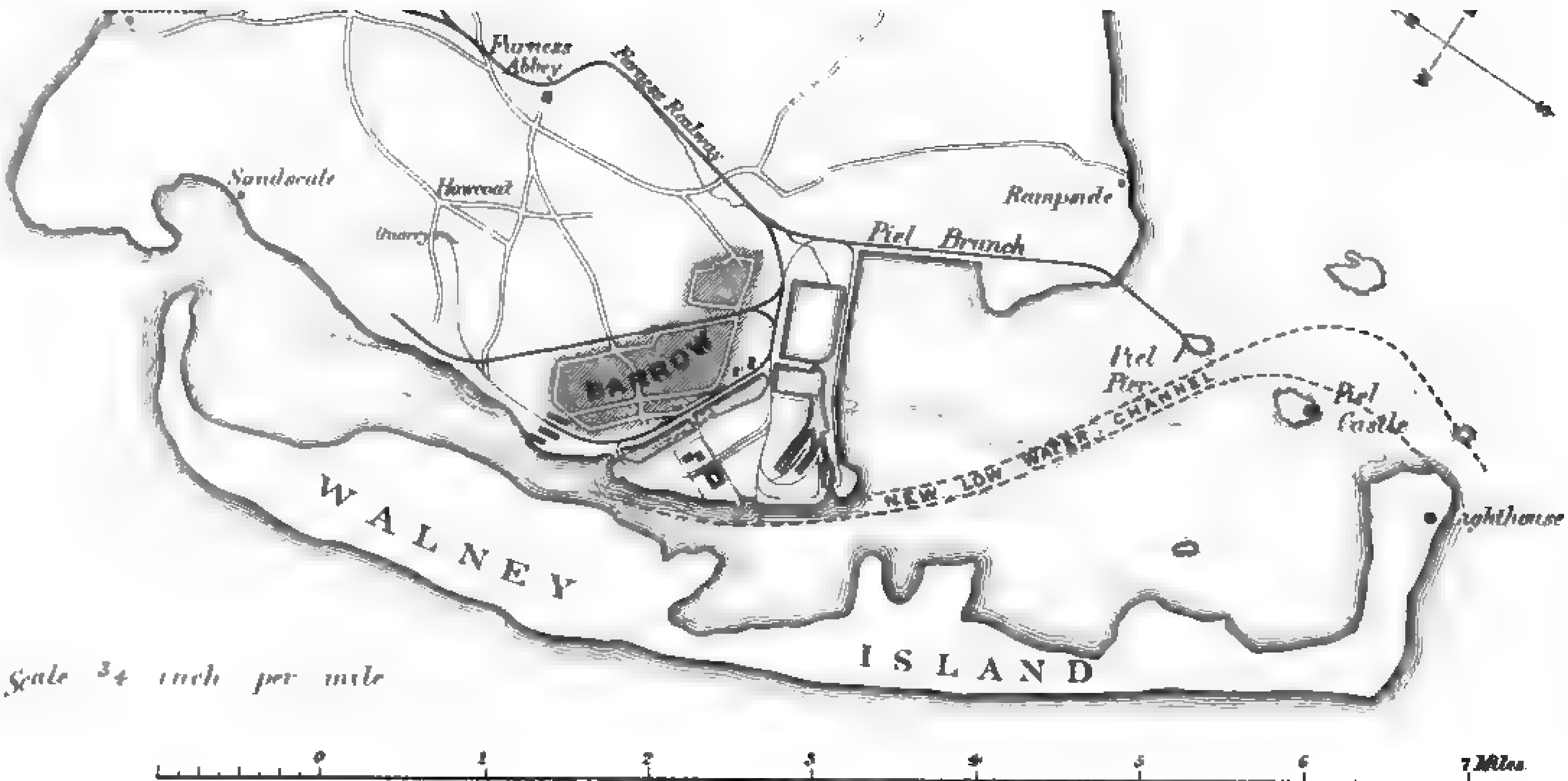


Fig. 10. *Plan.*

Plate 33.



Scale 3/4 inch per mile

Proceedings Inst M.E. 1880.

Plate 34

Fig 2.

Plan of Docks.

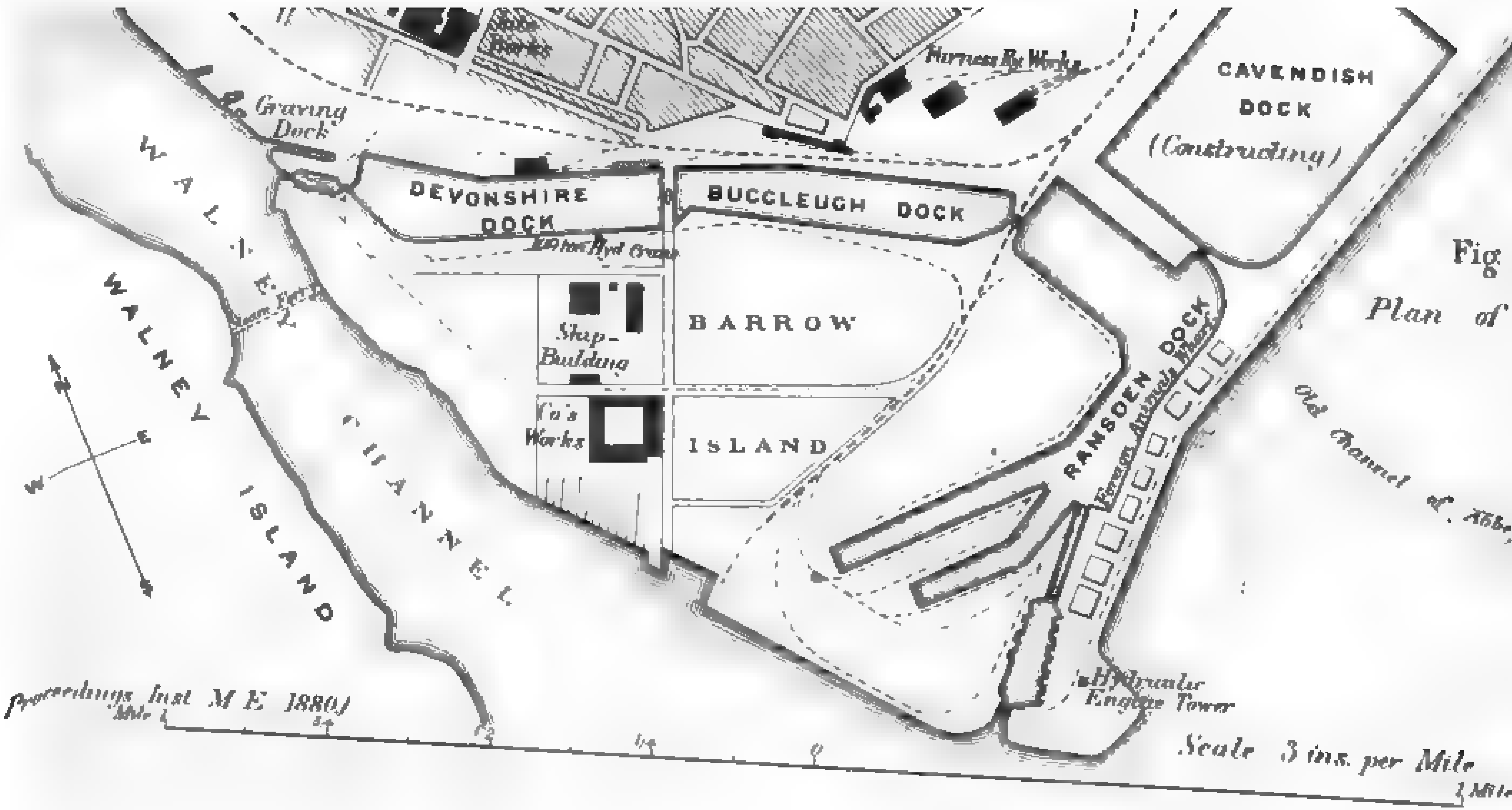


Plate 15

Fig. 3. Wall outside Entrance.

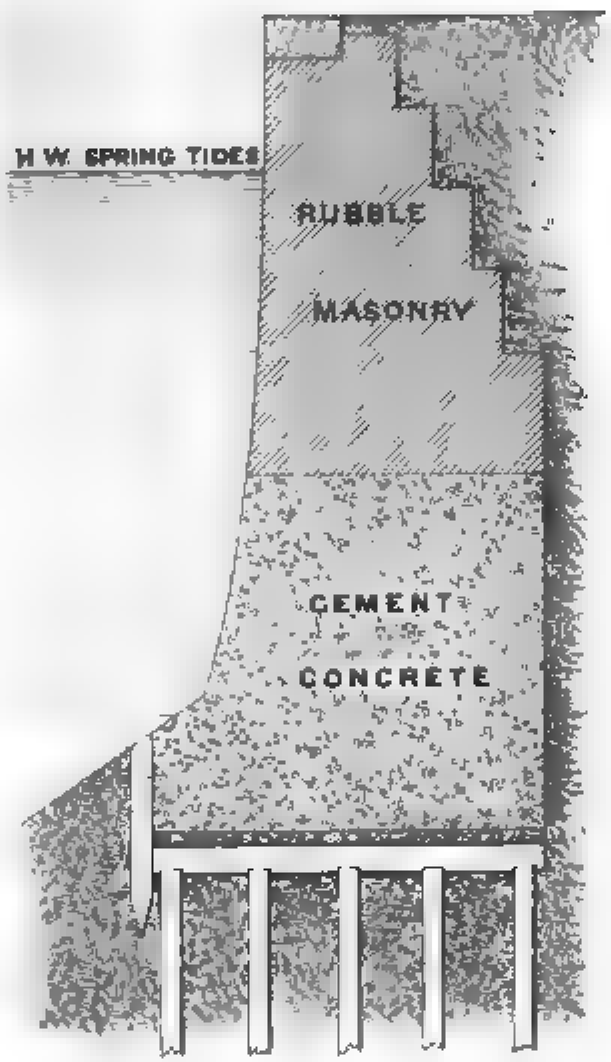
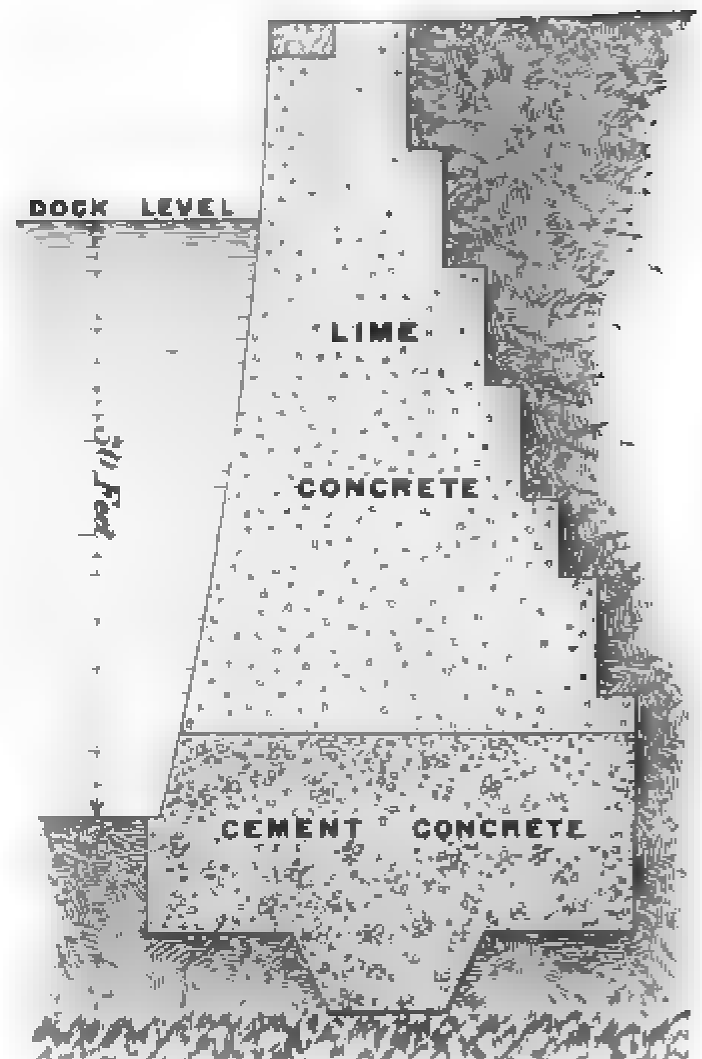
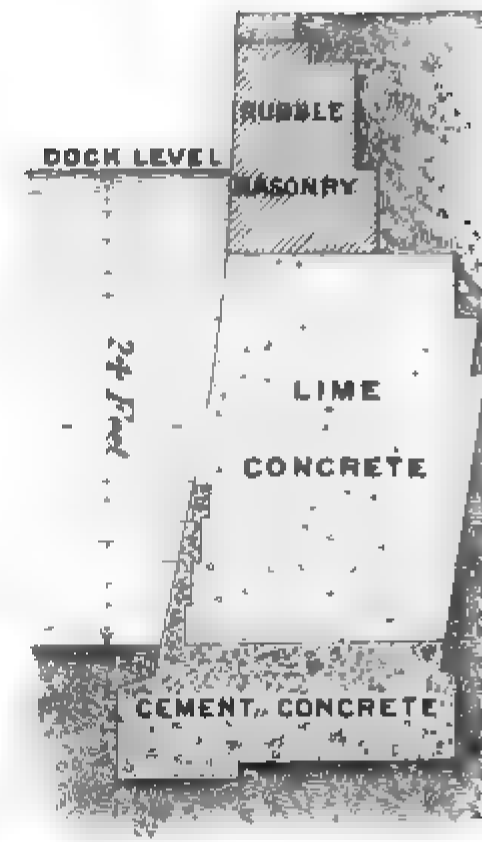


Fig. 4 Wall in Tidal





Scale 1/200th

(Proceedings Inst. M. E. 1880)

Buccleuch Dock Bridge

Fig. 6.

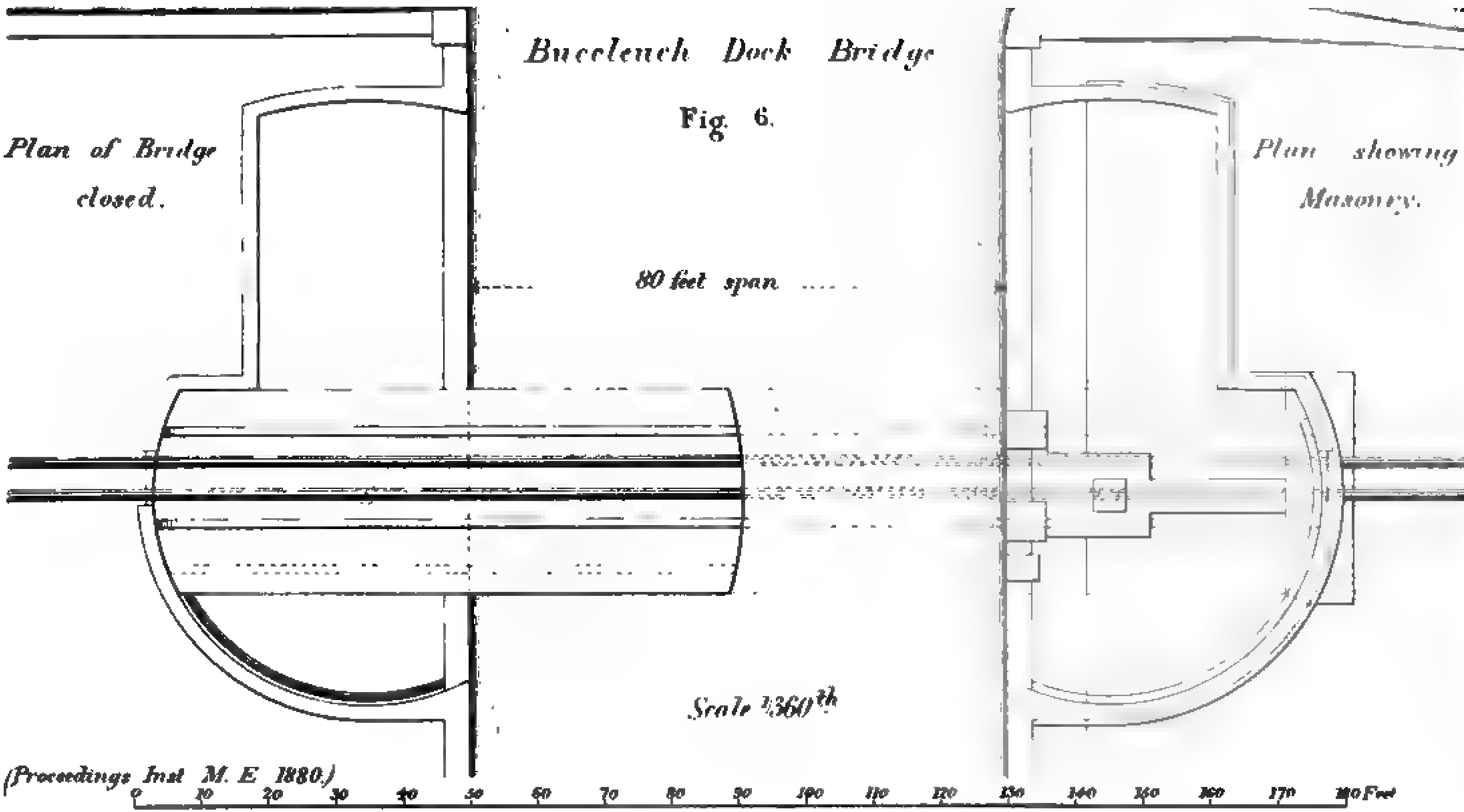


Plate 37.

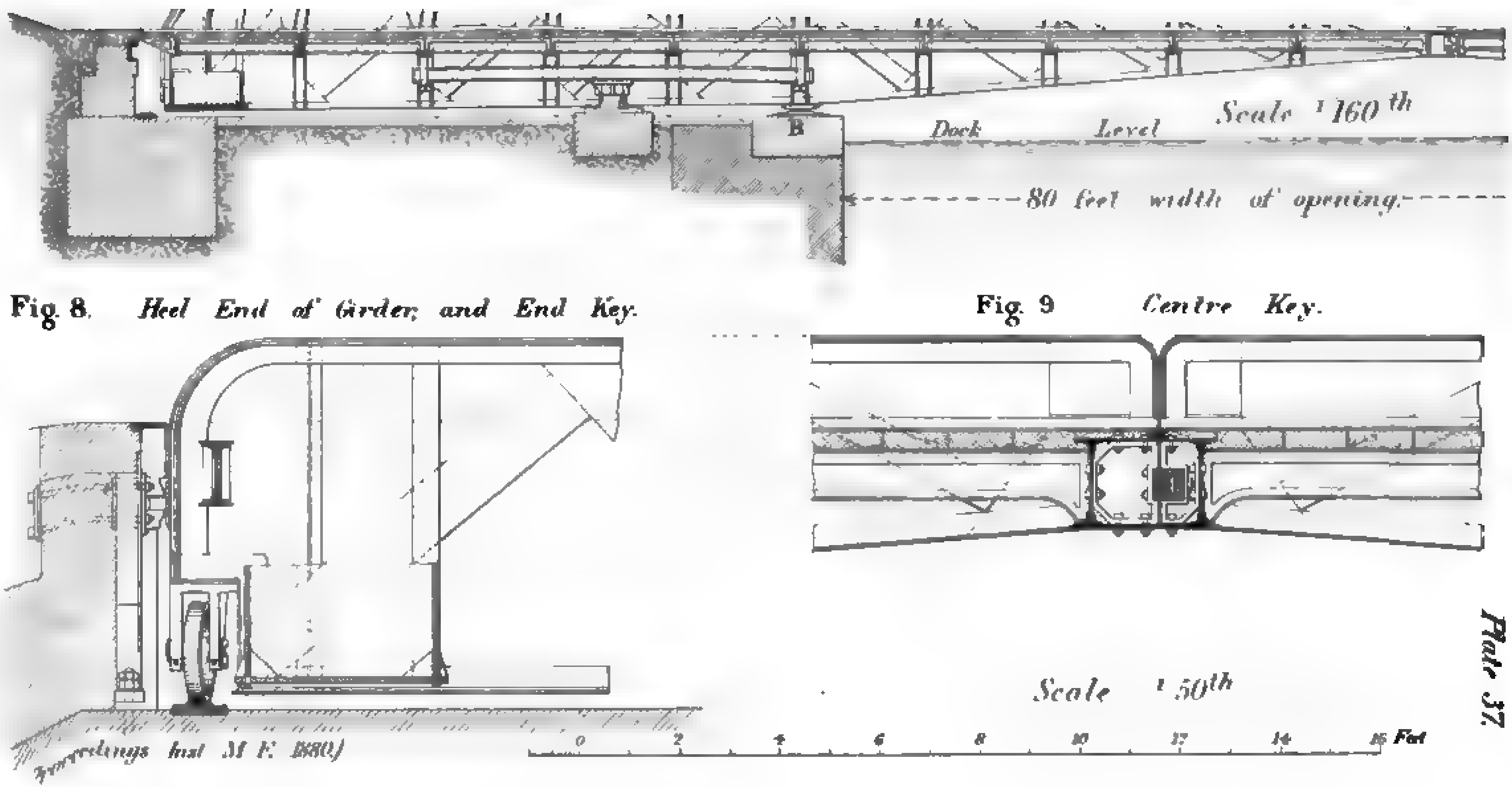


Fig. 8. Heel End of Girder, and End Key.

Fig. 9 Centre Key.

(Proceedings Inst M. E. 1880)

Plate 38.

Fig. 10. *Elevation of Spring Girders.*

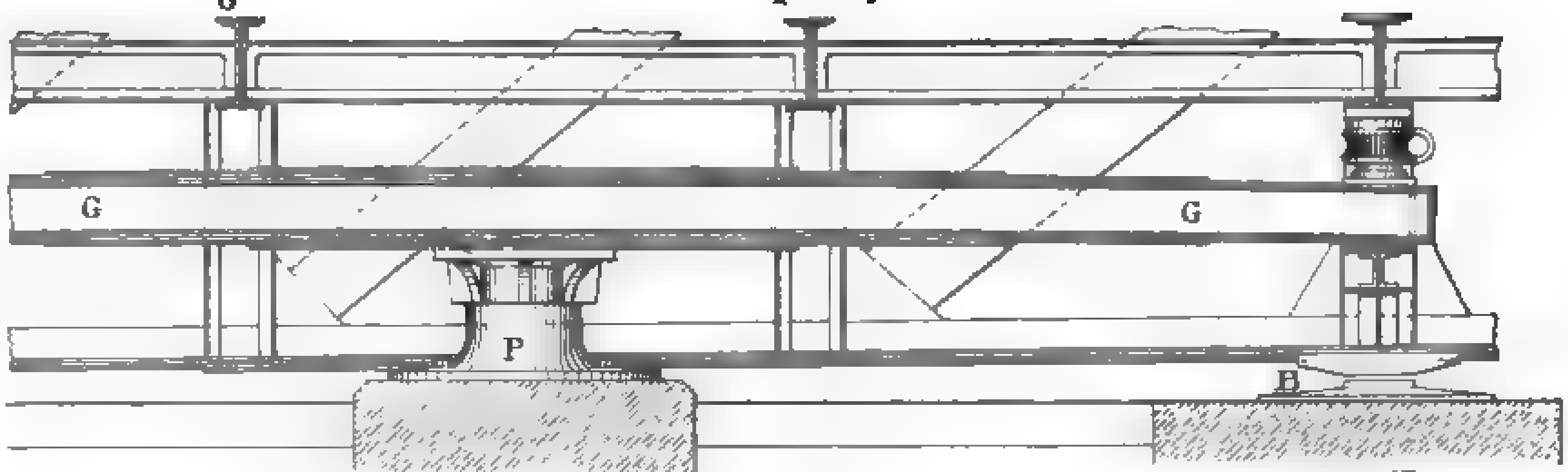


Fig. 12. *Transverse Section at centre.*

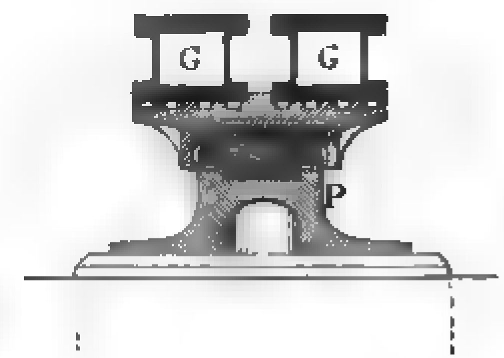


Fig 11 *Plan of Spring Girders.*

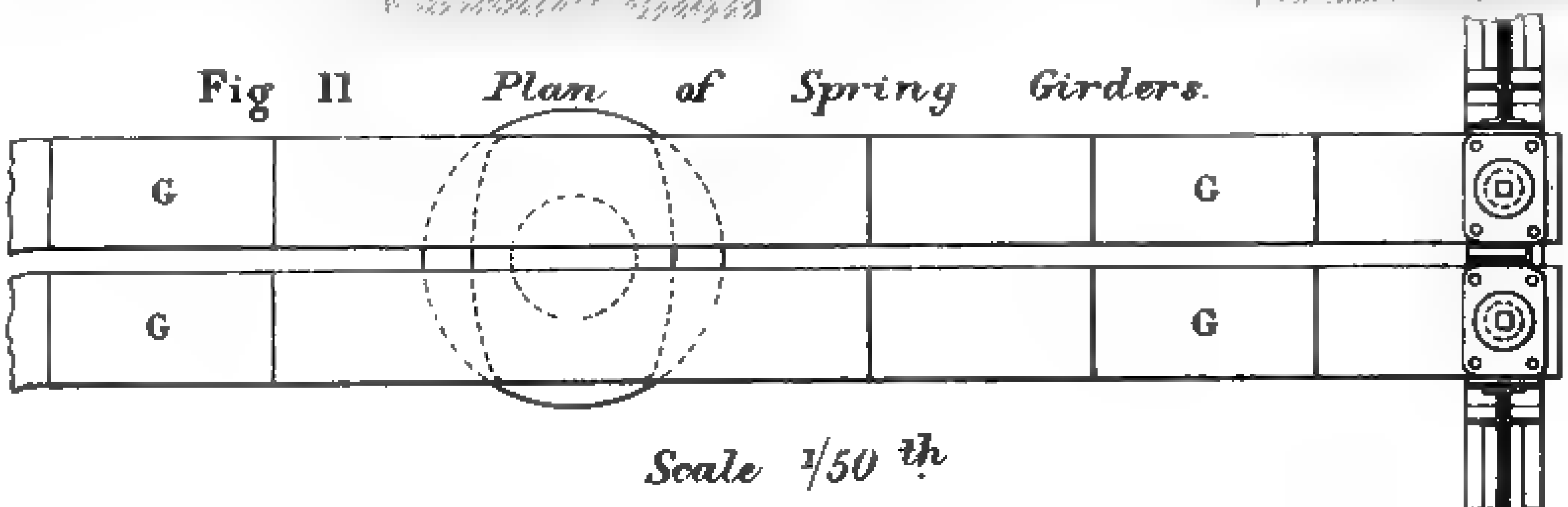


Fig. 13. *Transverse Section at ends.*

Scale 1/50 th

Ins. 12 0 2 4 6 8 10 12 14 16 Feet.

(proceedings Inst. M. E. 1880.)

[illegible]

[redacted]

Plate 39.

Fig. 1. *General Profile.*

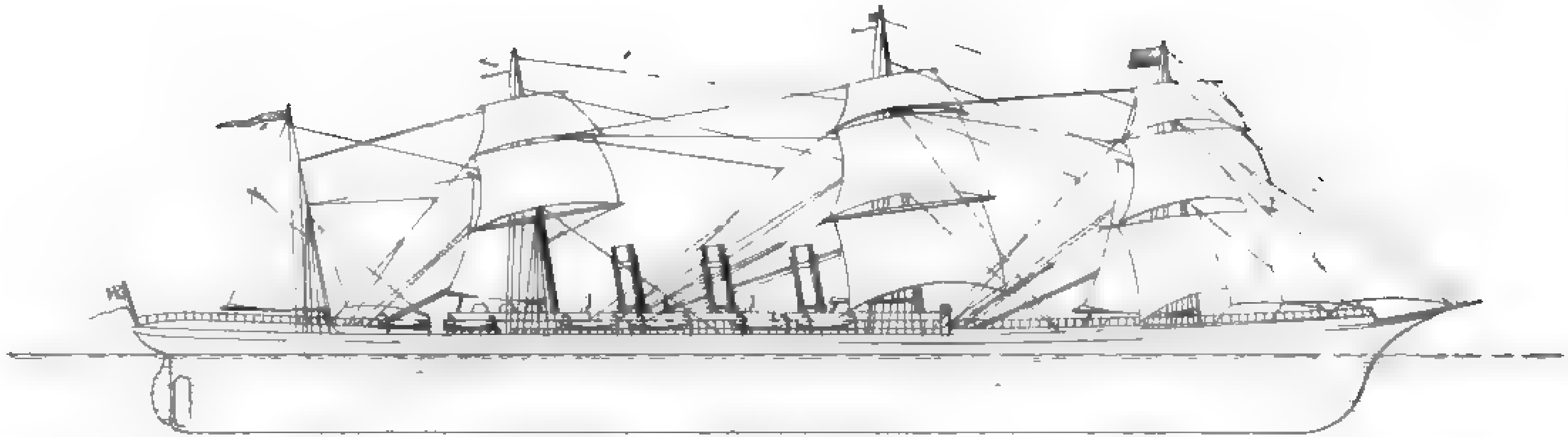
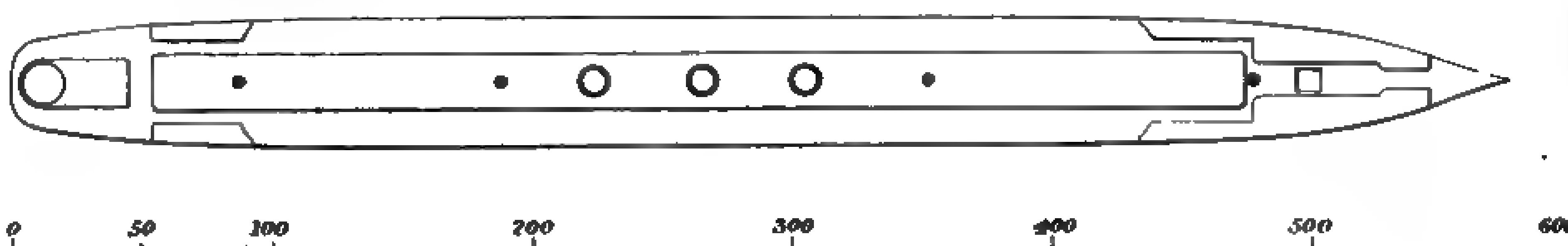


Fig. 2. *Plan.*



(Proceedings Inst. M E. 1880.)

Scale $^1/_{1200}$th

Plate 40.

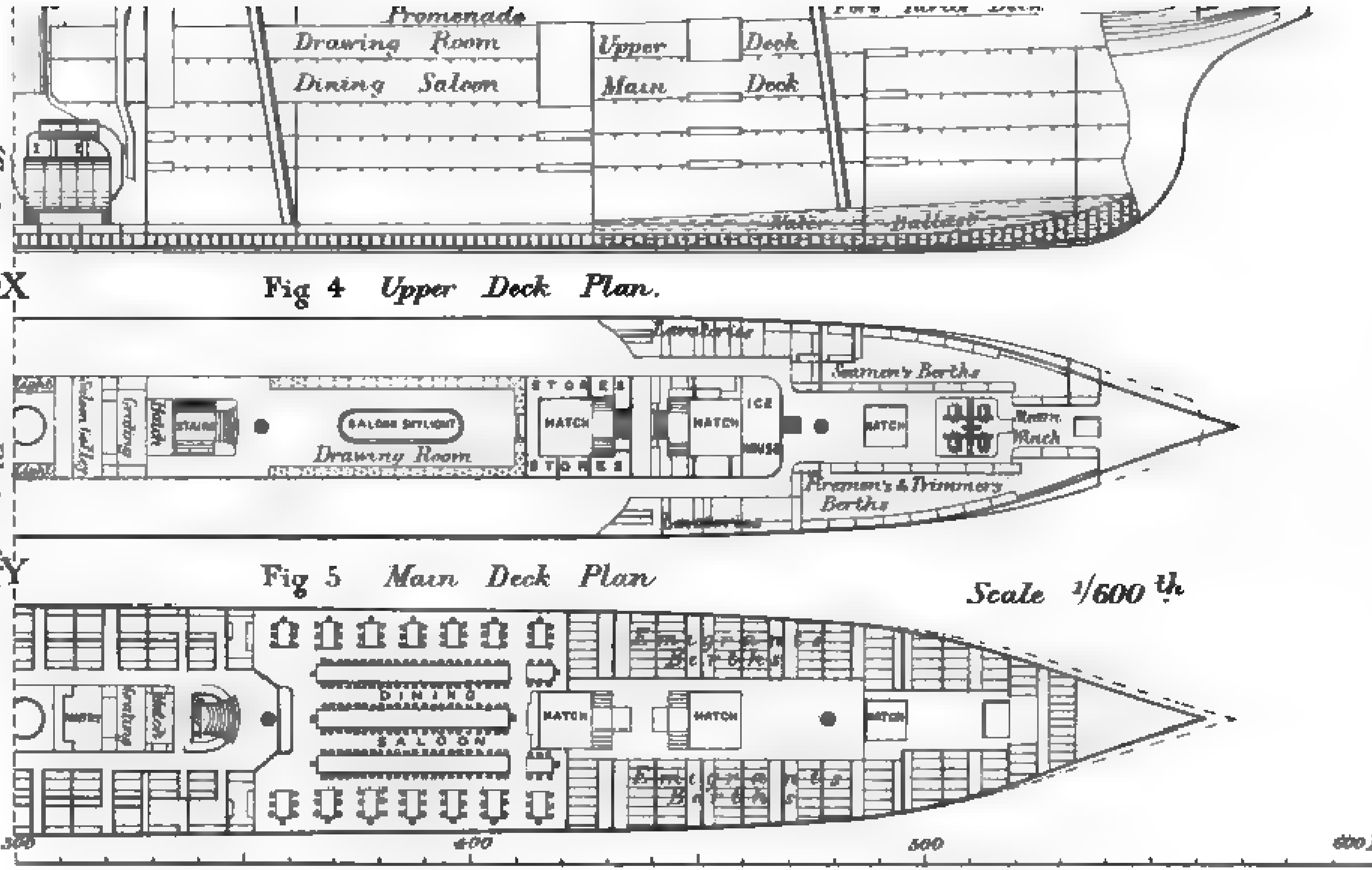


Fig 4 Upper Deck Plan.

Fig 5 Main Deck Plan

Scale 1/600 th

(Continuation on Plate 41.)

[redacted]

Plate 41.

(Continuation on Plate 40.)

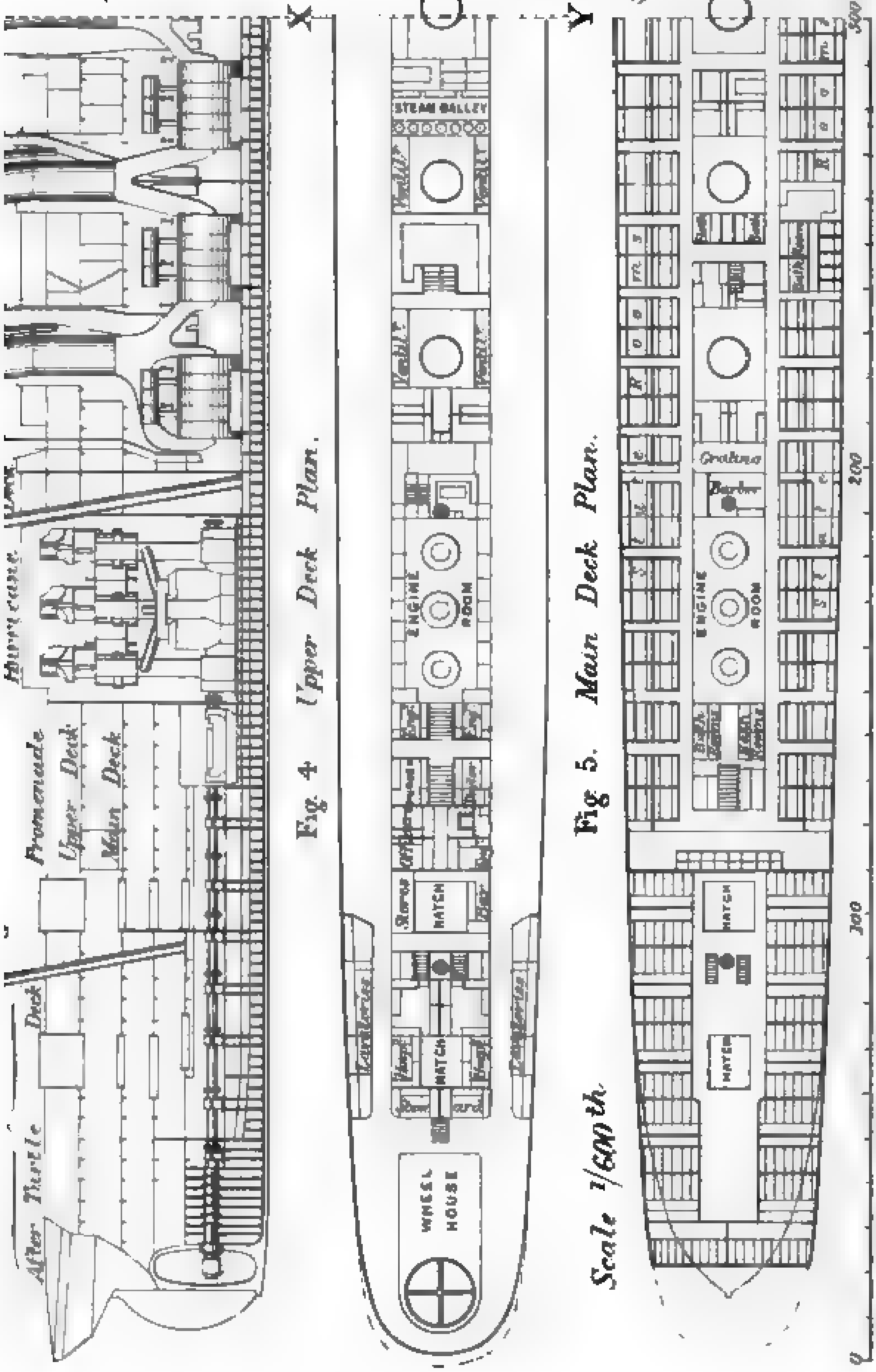


Fig. 4 Upper Deck Plan.

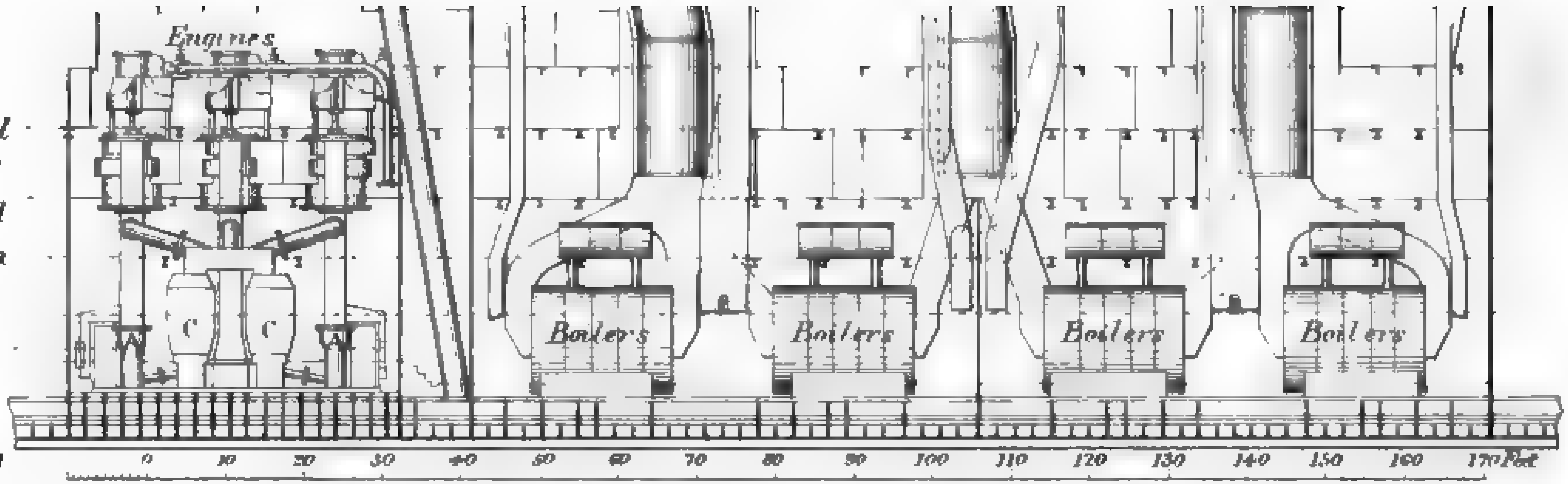
Fig. 5. Main Deck Plan.

Scale 1/600th

Plate 42.

Fig 6.

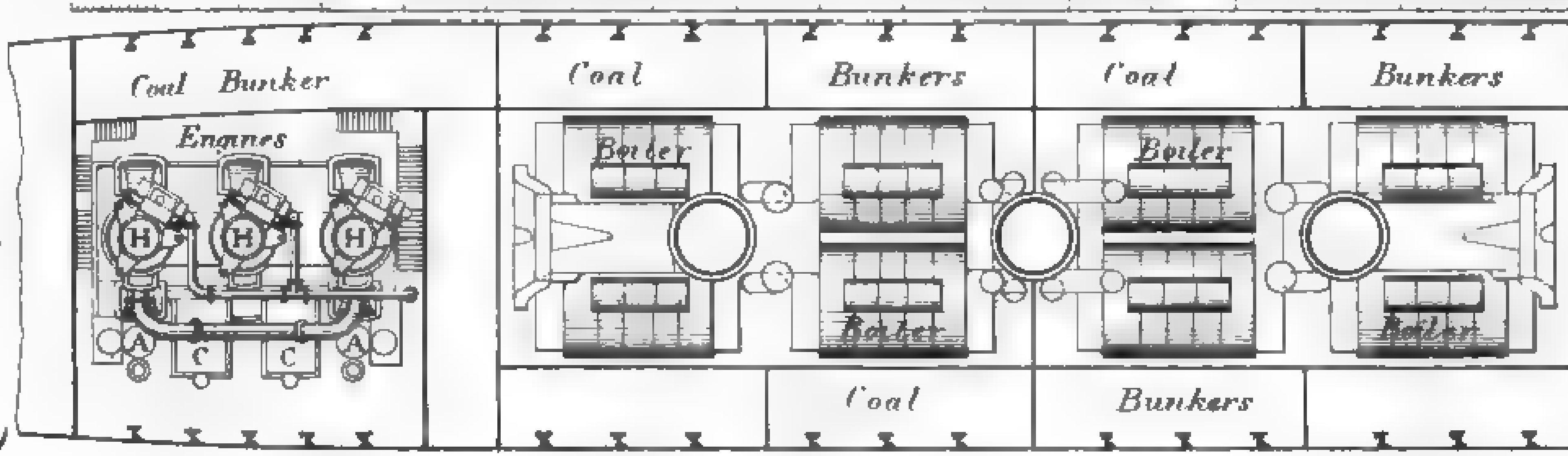
Longitudinal Section of Engine and Boiler Room



Scale 1/360th

Fig 7.

Plan of Engine and Boiler Room.

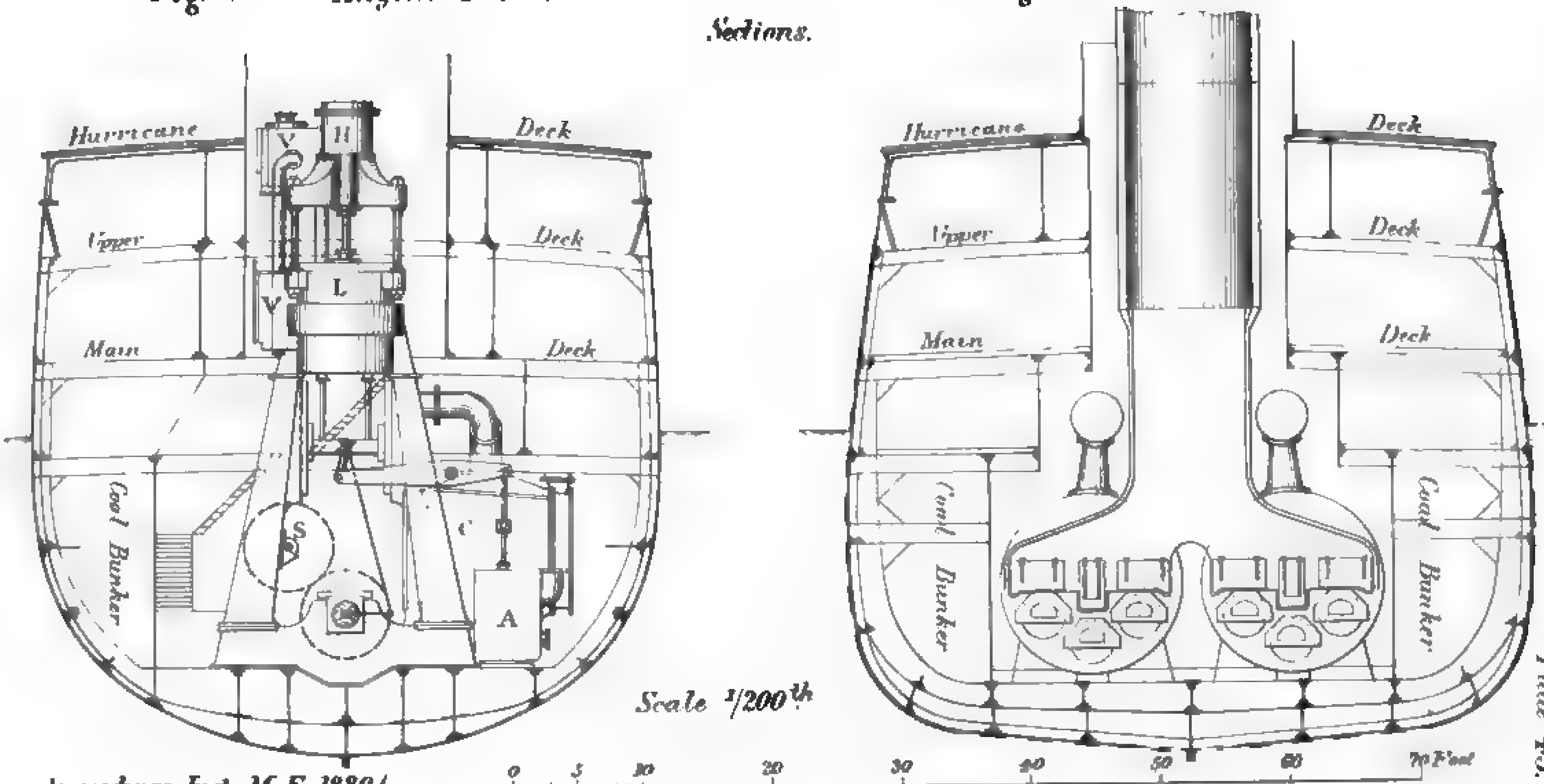


ceedings (I.E. 1880)

STEAM-SHIP "CITY OF ROME"

Plate 43.

Fig. 8 Engine Room. Transverse Sections. Fig. 9. Boiler Room.

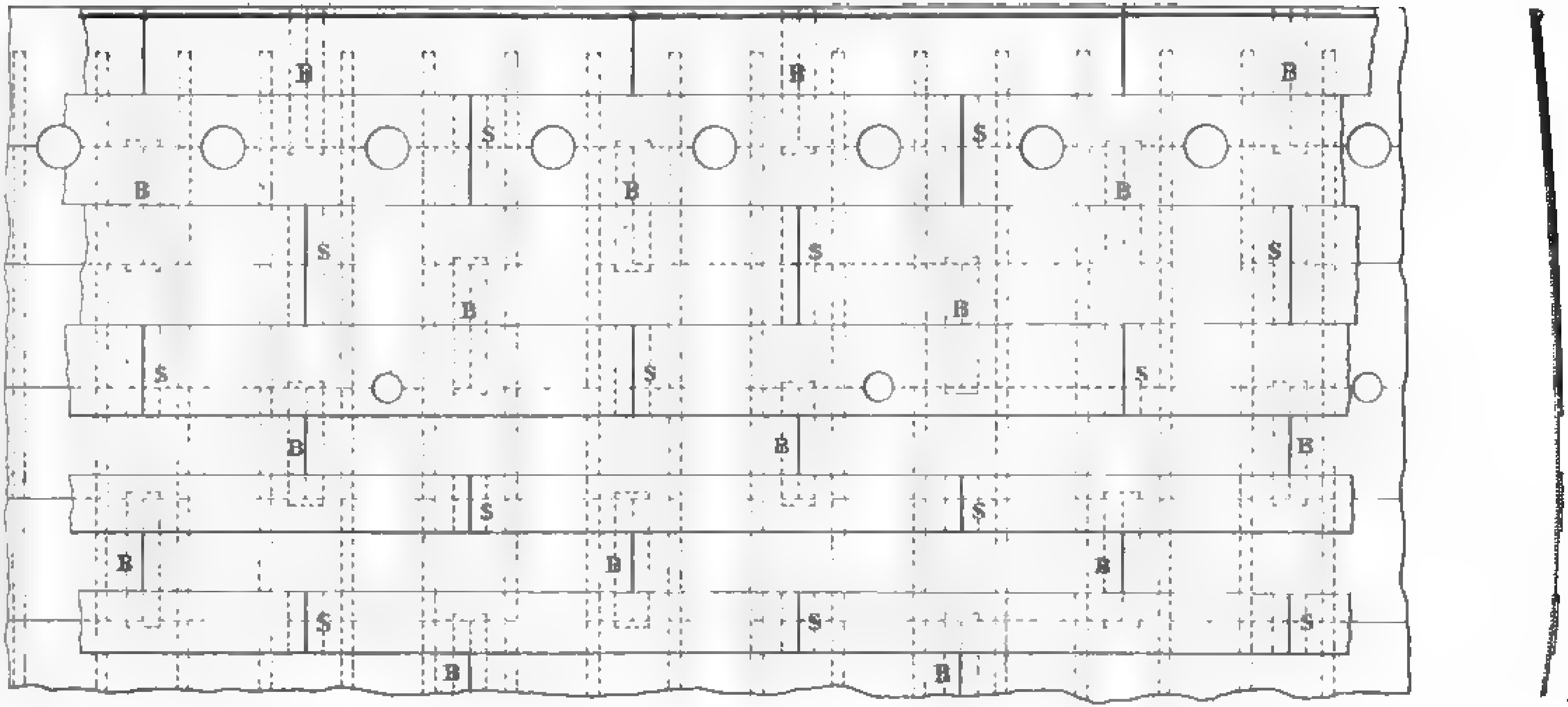


Scale 1/200th

Plate 43.

(Proceedings Inst. M. E. 1880.)

Fig 10 Outside Elevation of Plating



(Proceedings Inst. M. E 1880.)

Ins. 12 0 2 4 6 8 10 12 14 16 18 20 Feet.

Scale 1/70th

Plate 11

Hollow Built-up Crank-Shaft of Fluid-Compressed Steel.

Fig. 12.
Side Elevation.

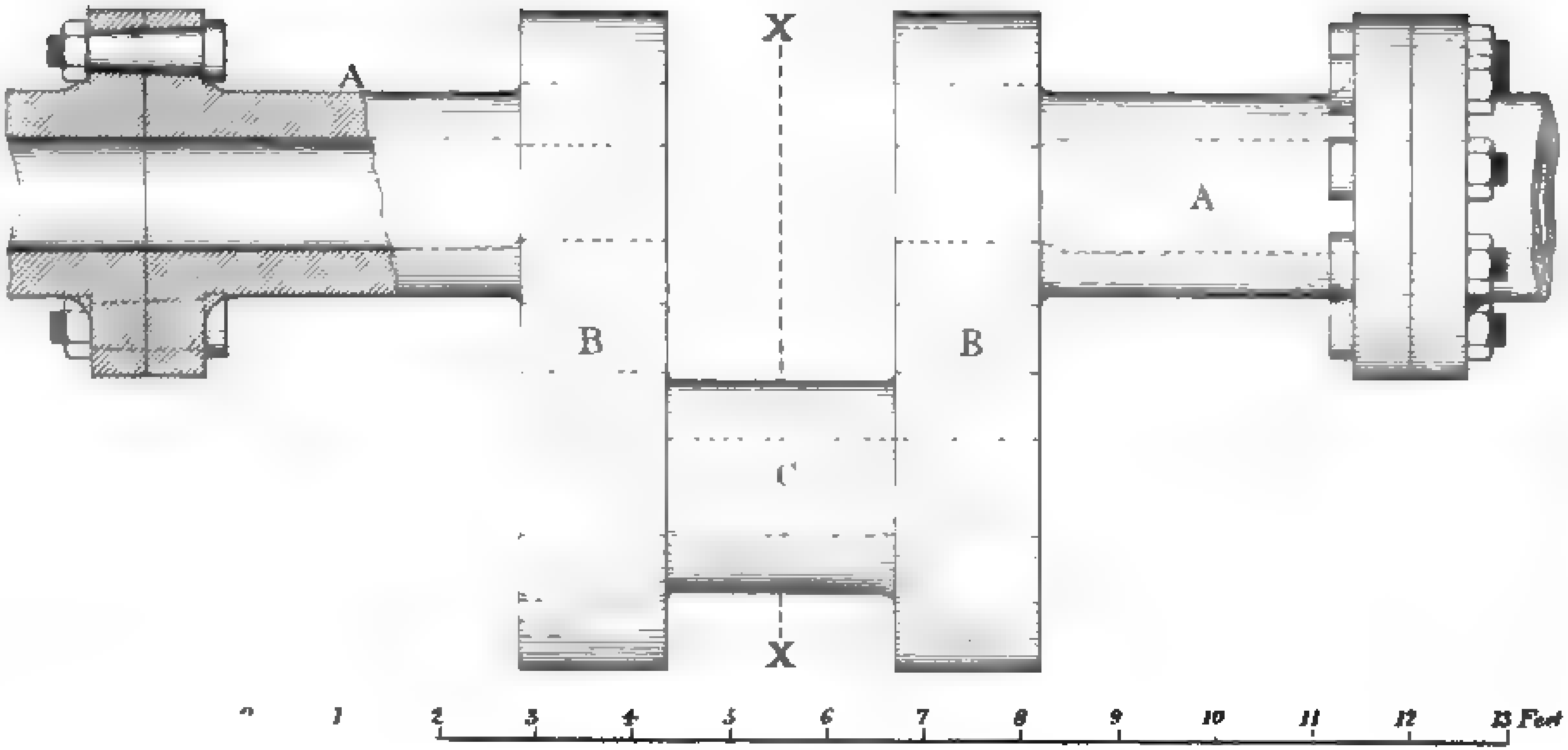
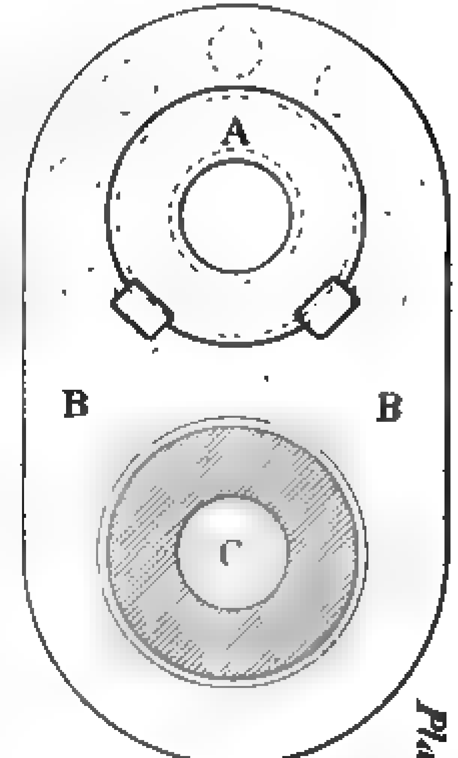


Fig. 13.
Transverse Section at XX.



Scale 1/30th

Plate 45.

FURNESS IRON MINES. *Plate 46.*

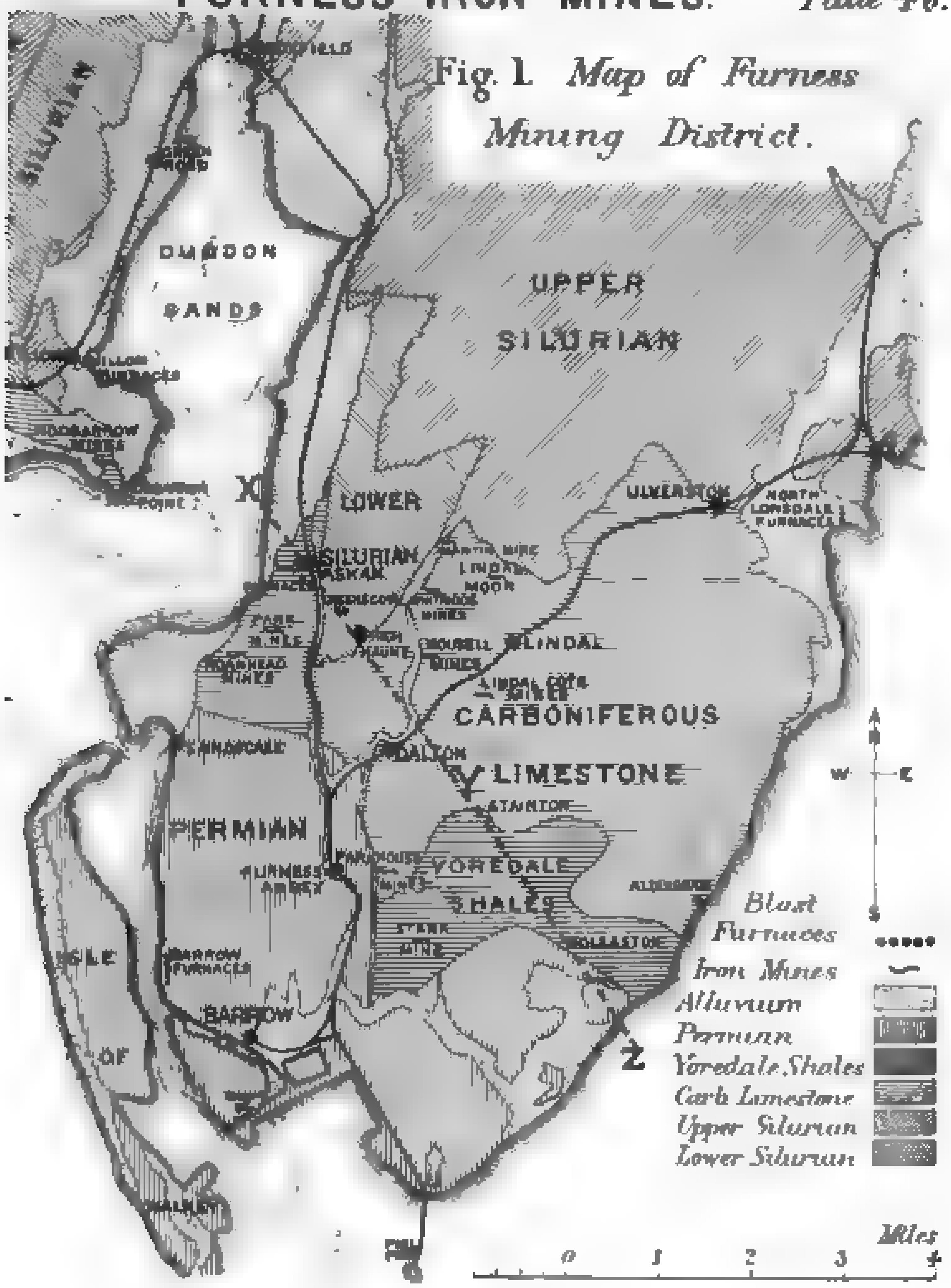


Fig. 1. *Map of Furness Mining District.*

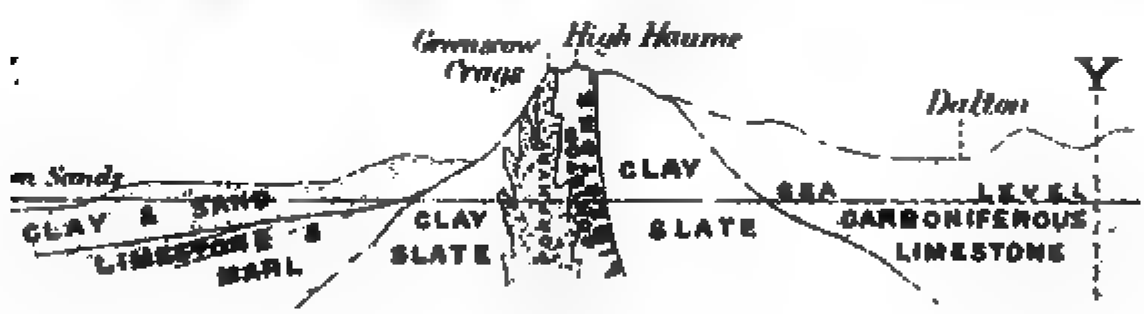
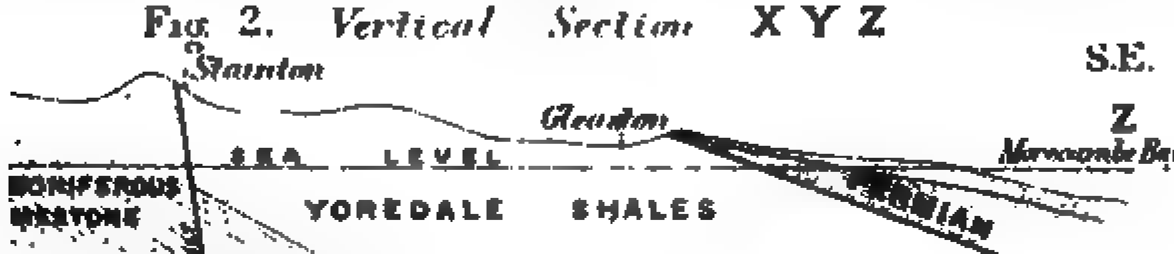


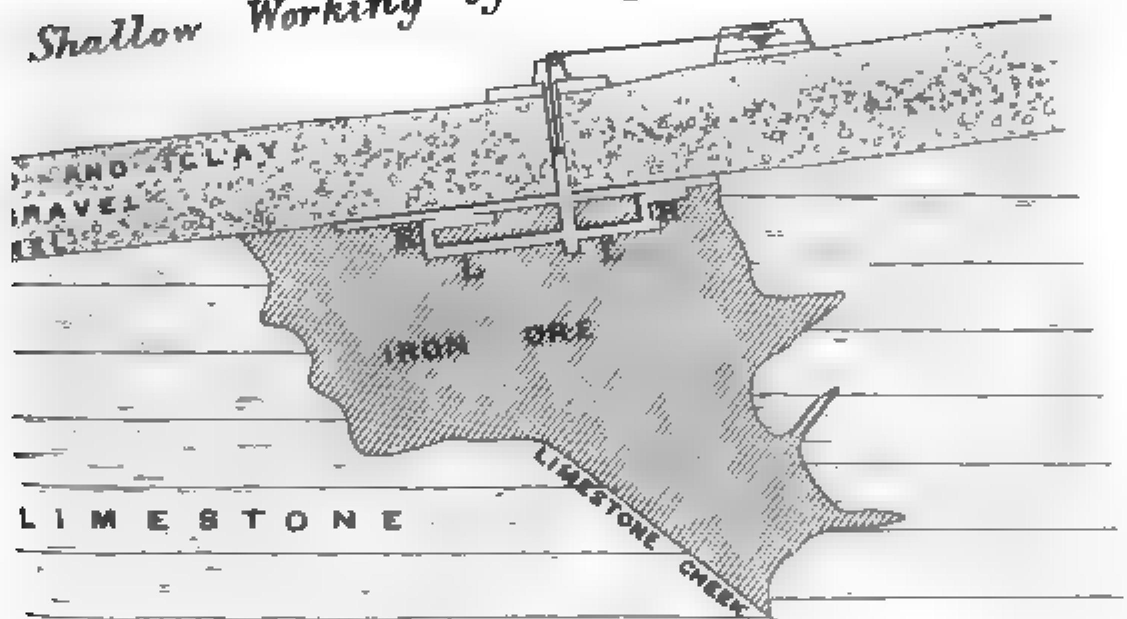
Fig. 2. *Vertical Section* X Y Z



Horizontal Scale 1 Inch = 1 Mile
Vertical Scale 1 Inch = 1000 Feet.

FURNESS IRON MINES. *Plate 47.*

Shallow Working by temporary Gin Pit.



4. Deeper Working by permanent Shaft in Limestone.

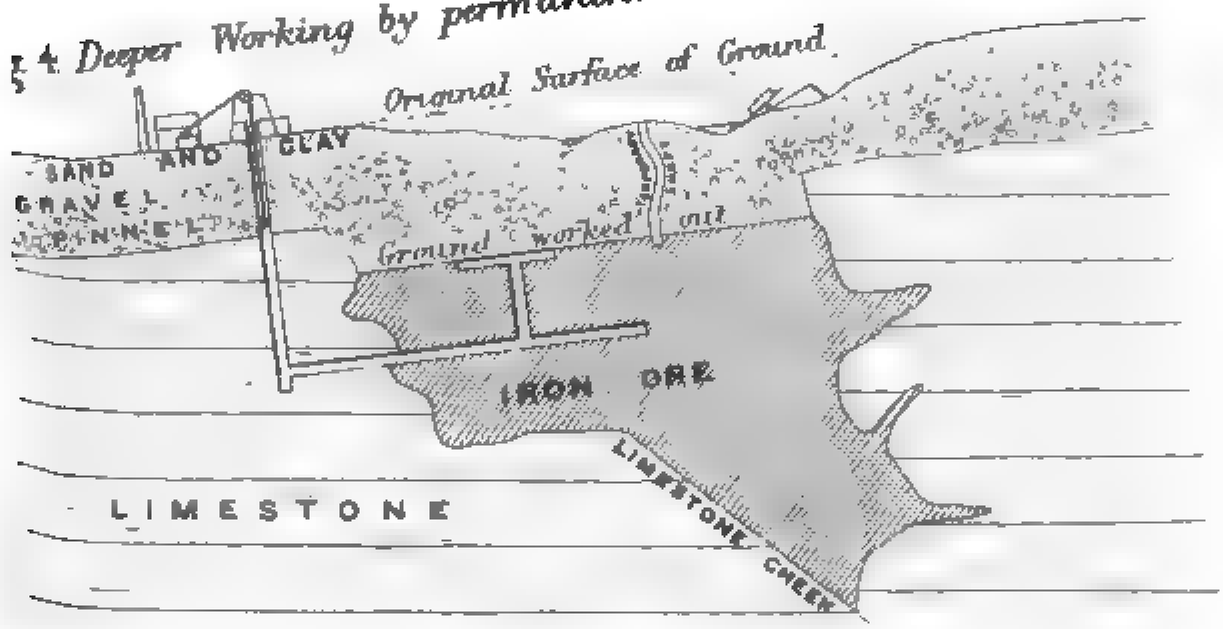
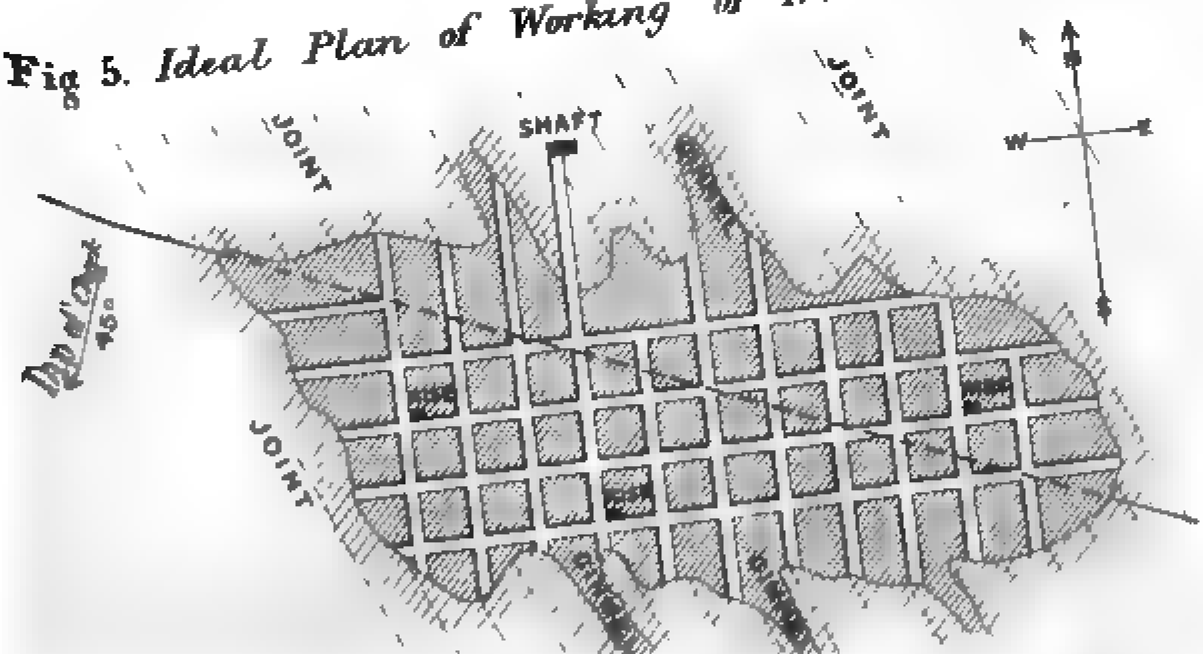
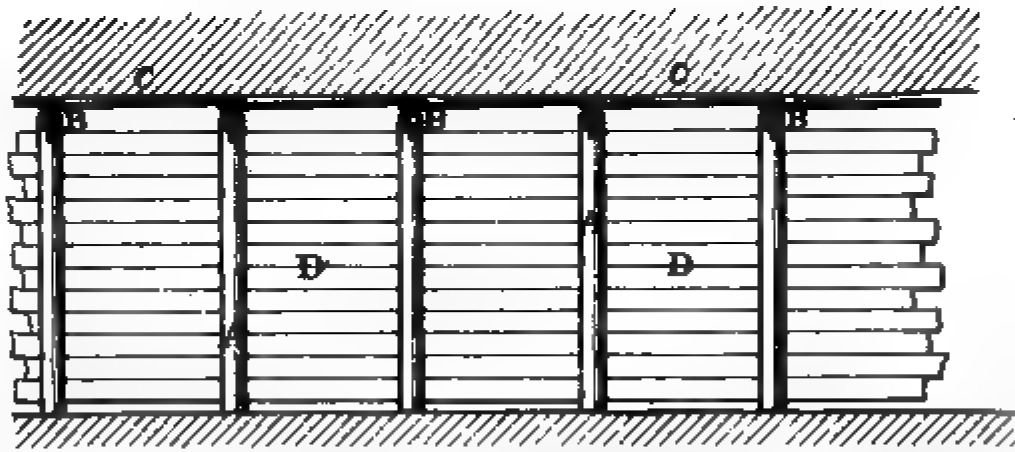


Fig 5. *Ideal Plan of Working of Iron Ore Basin.*





Working, showing Timbering

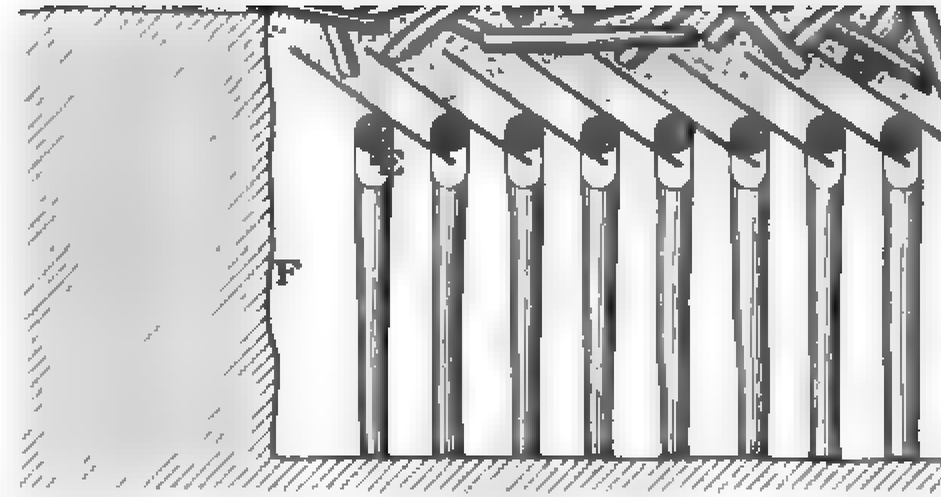


Fig 8. Transverse Section of 30 ft. Pillar and Driftways.

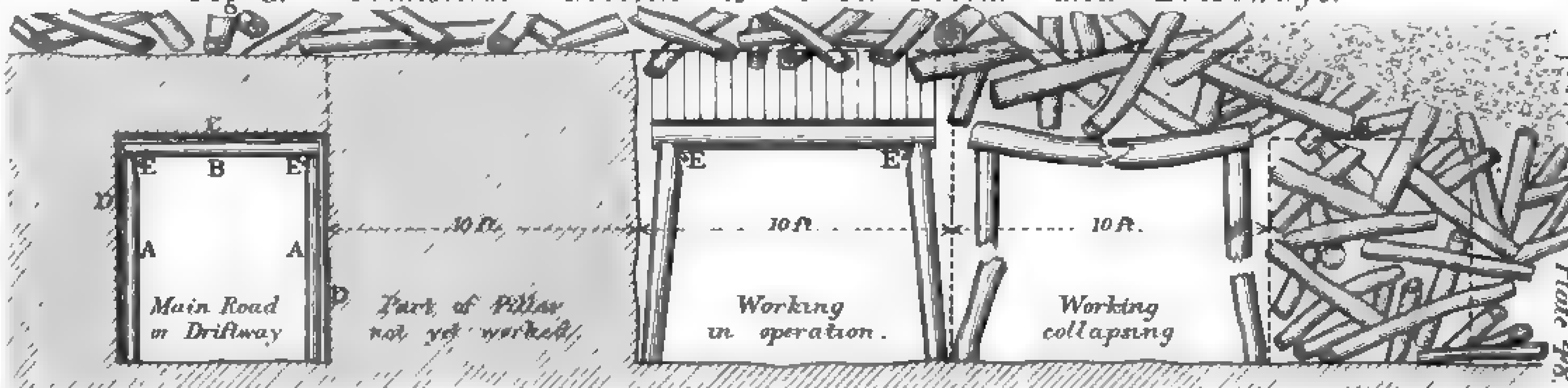


Plate 48.

(Proceedings Inst M E. 1880.)

Section of Fluted Rollers.

Scale 1/8th

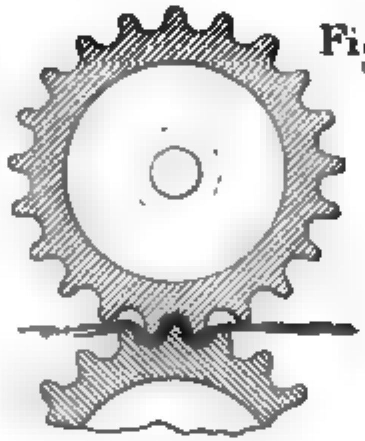
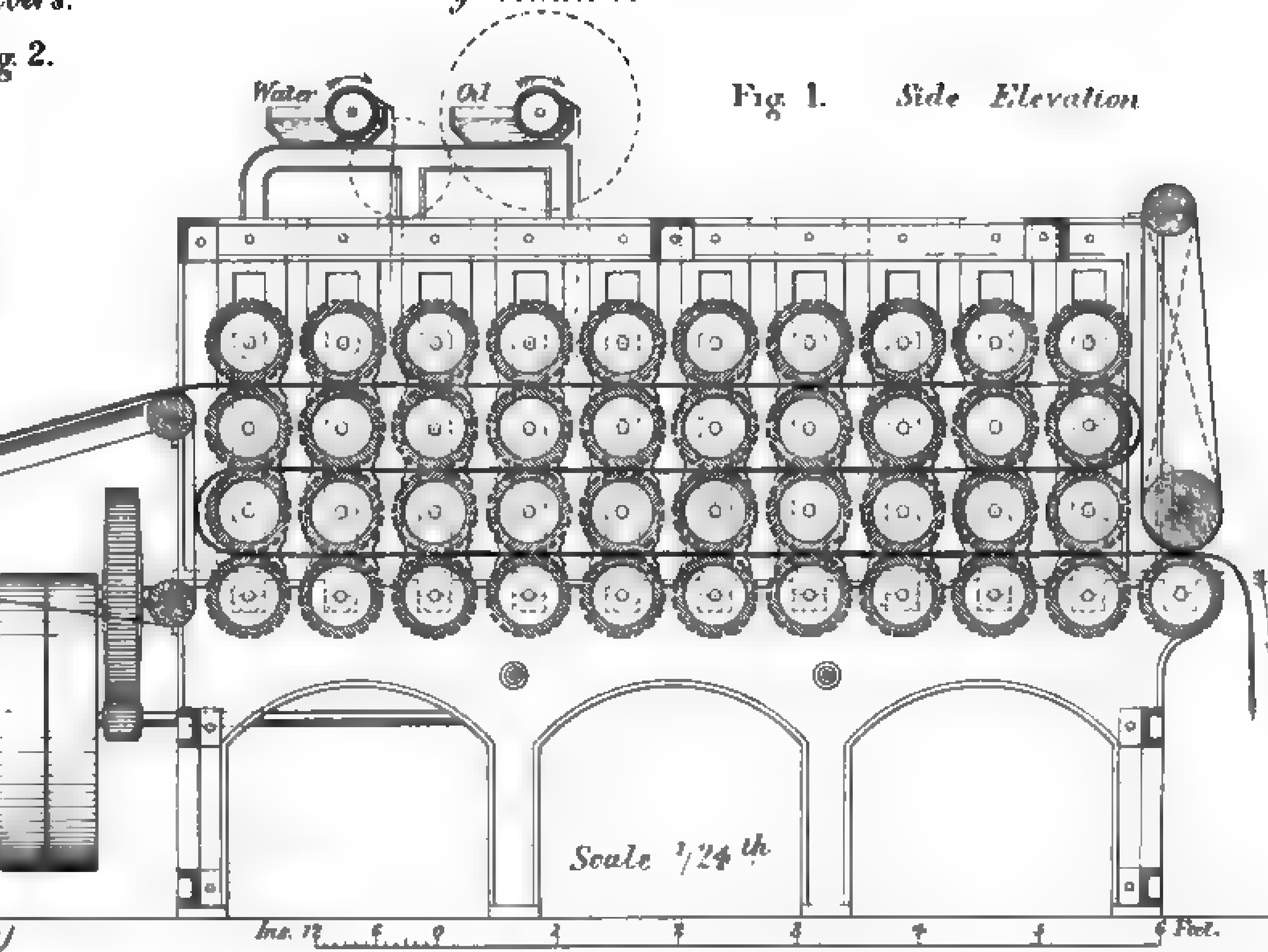


Fig. 2.

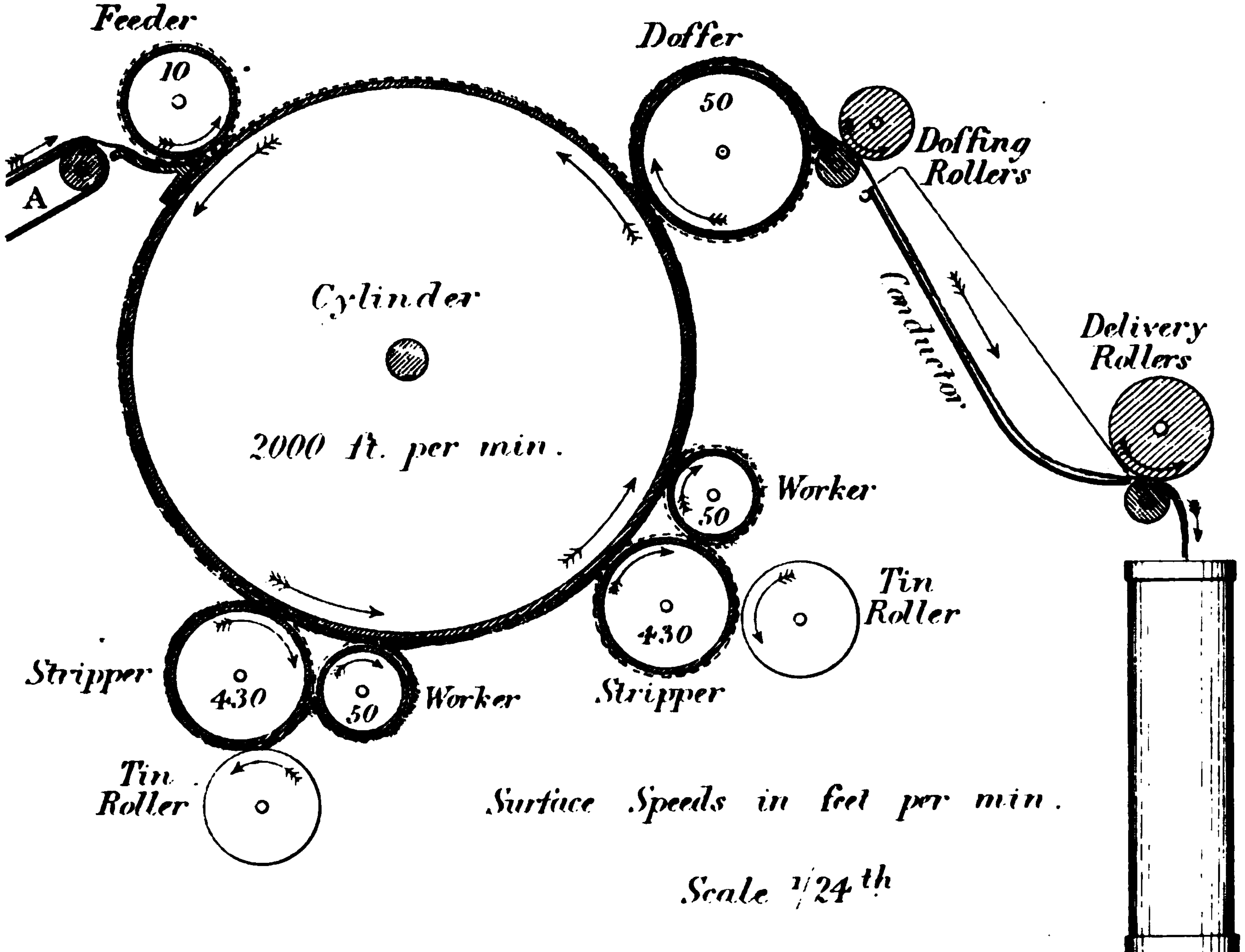
Softening Machine.

Fig. 1. Side Elevation



[redacted]

Fig. 3. Breaker Card.

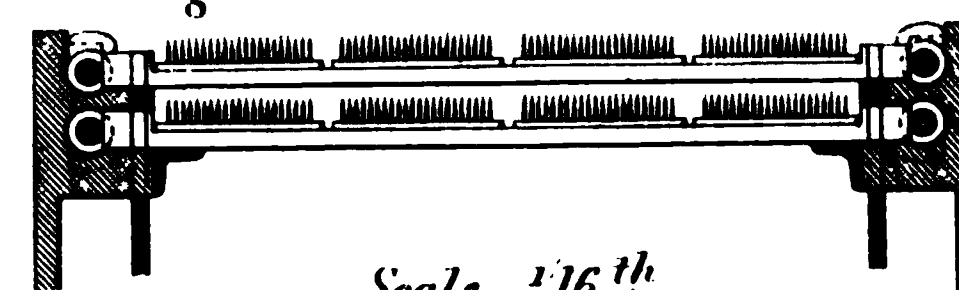


Surface Speeds in feet per min.

Scale 1/24th

Spiral-Gill Drawing Frame.

Fig. 5. Transverse Section.



Scale 1/16th

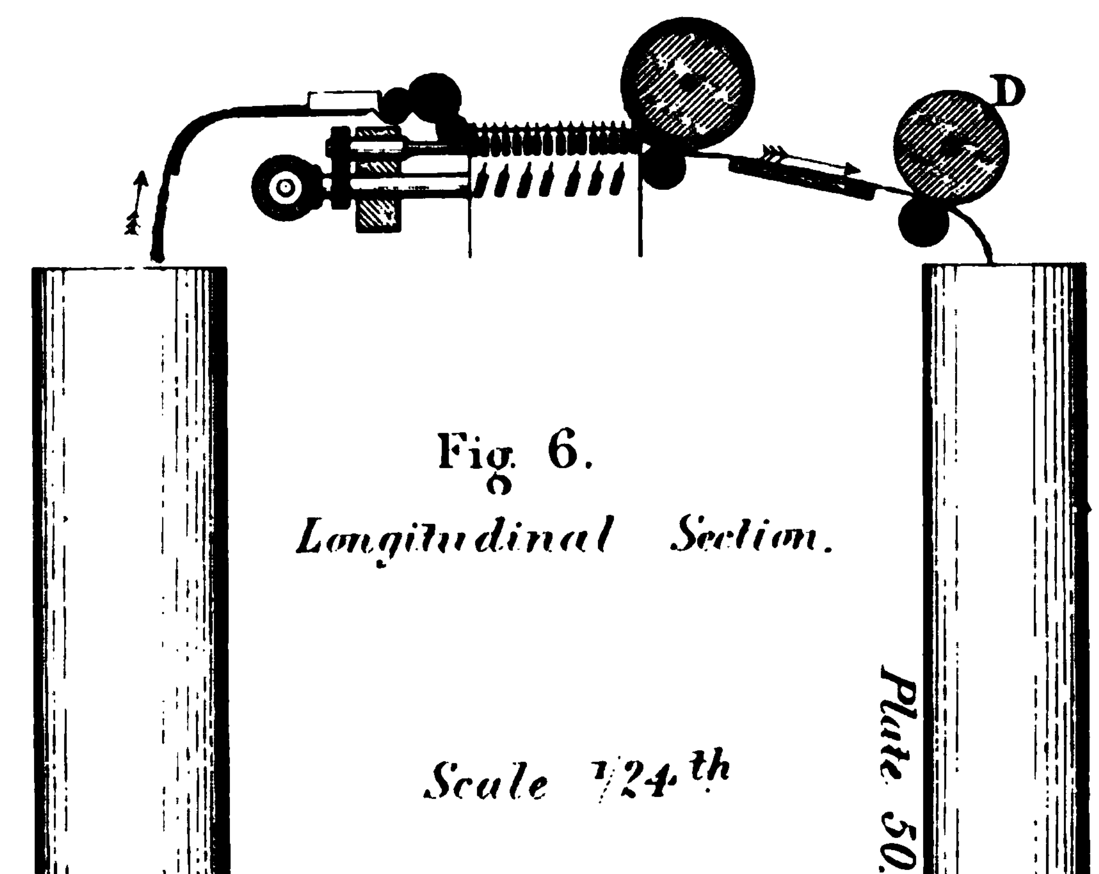


Fig. 6.

Longitudinal Section.

Scale 1/24th

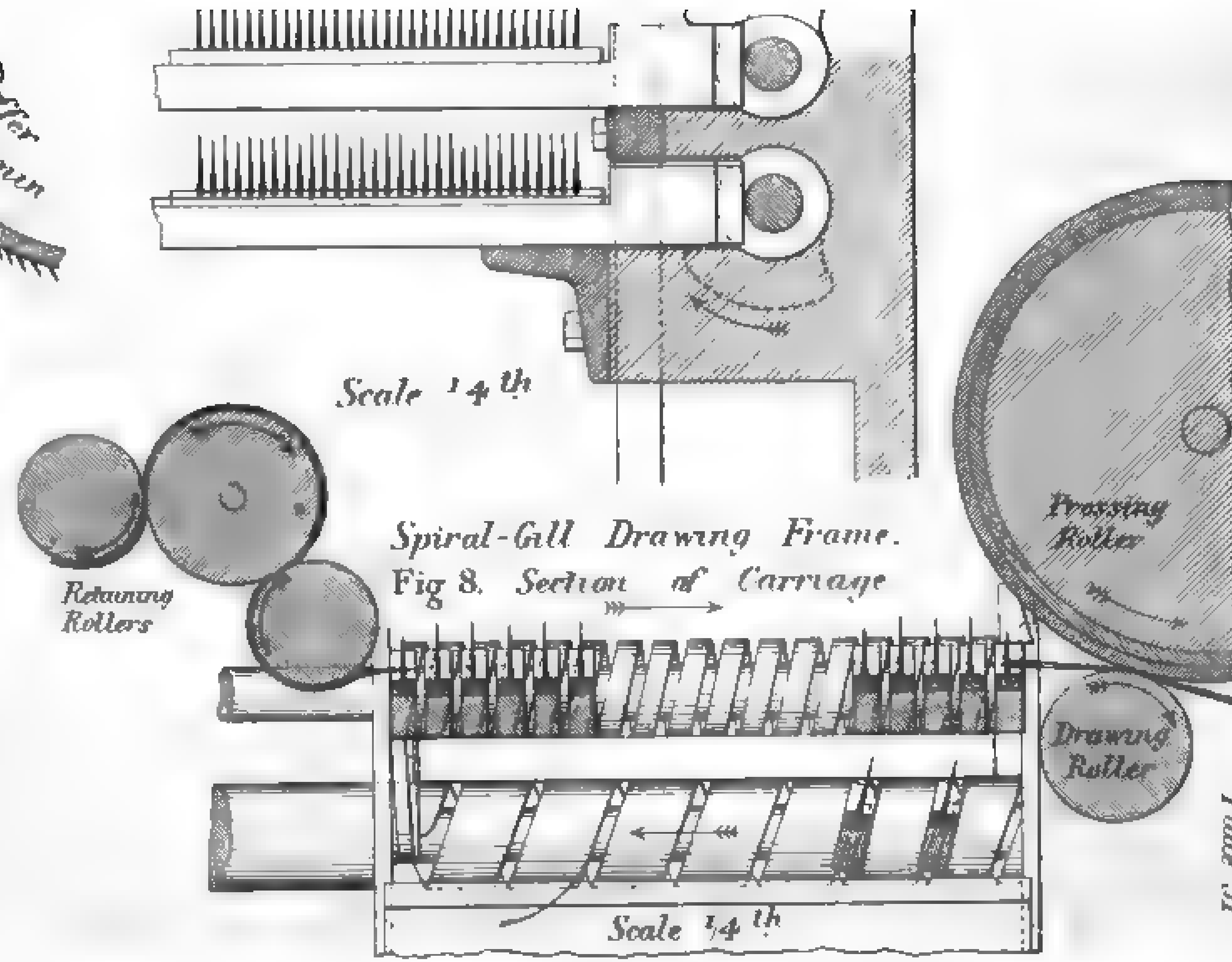
Plate 50.

Ins 12 6 0 1 2 3 4 5 6 Feet.

(Proceedings Inst. M. E. 1880.)

Plate 51

Fig. 4.
Breaker Card
Cylinder
Scale 1/8 th



Spiral-Gill Drawing Frame.
Fig 8. Section of Carriage

(Proceedings Inst. M. E 1880.)

Plate 52.

Fig. 9. Roving Frame.

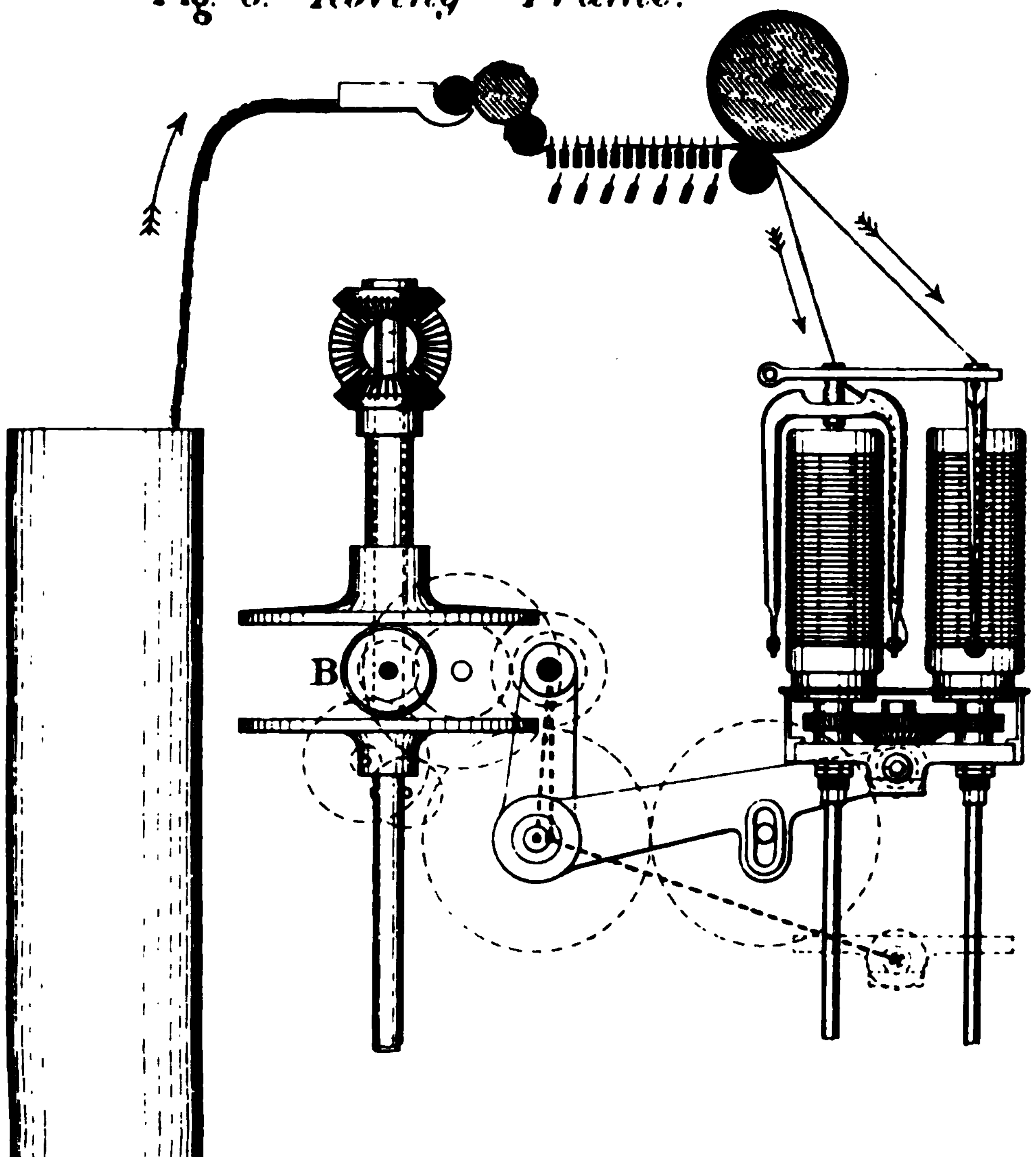


Fig. 10. Regulating Motion of Roving Frame.

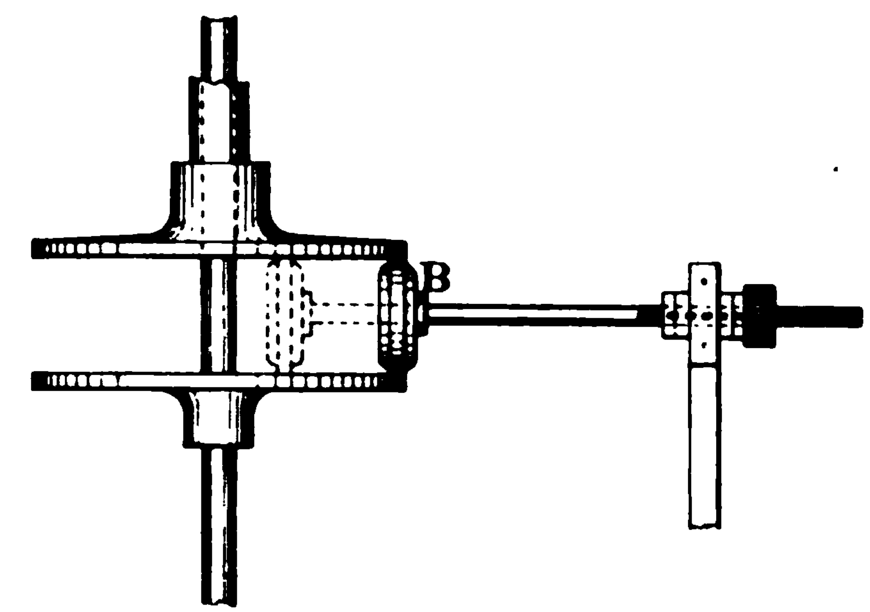
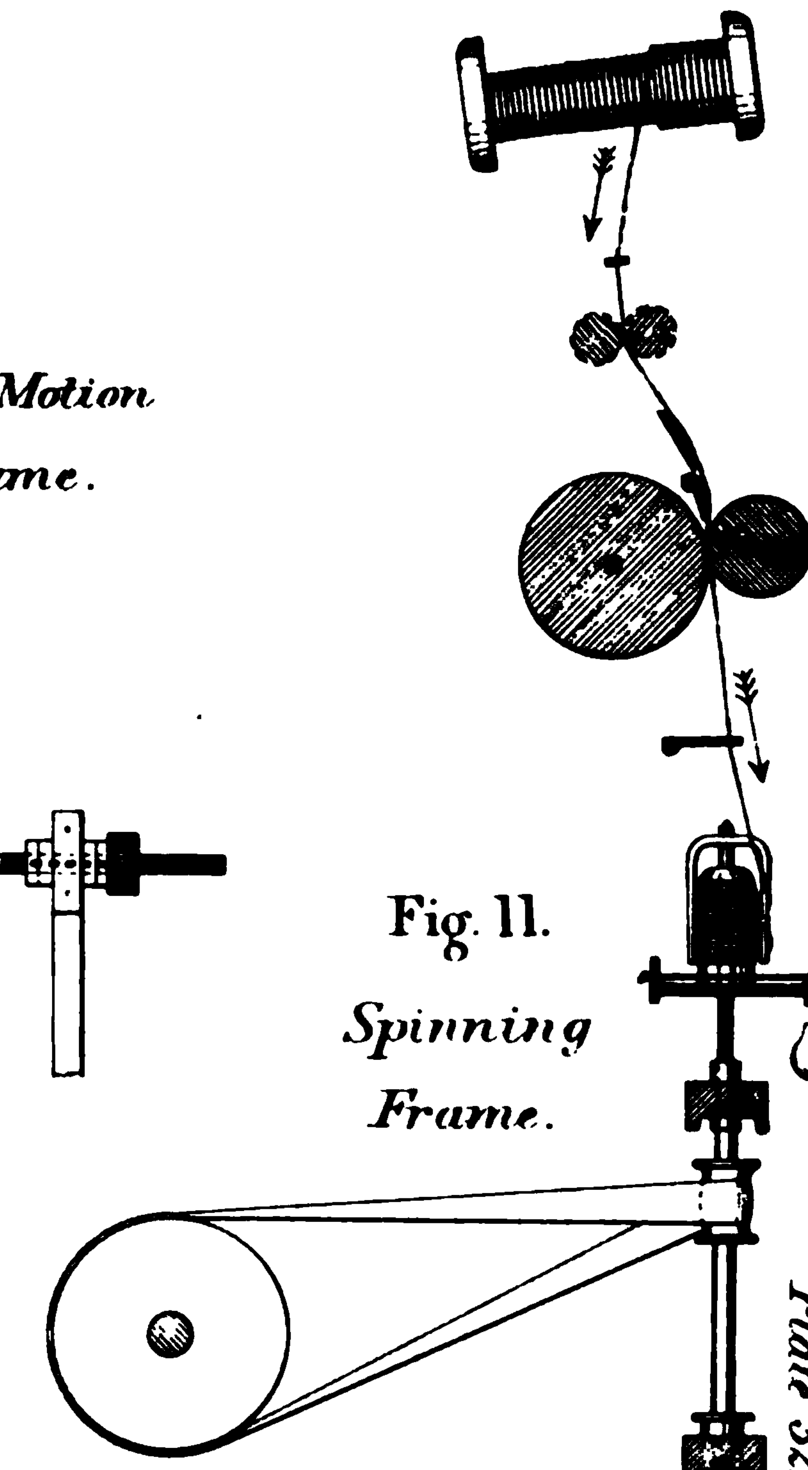


Fig. 11. Spinning Frame.



Scale 1/16 th

(Proceedings Inst. M. E. 1880.)

STEEL-COMPRESSION BY STEAM. *Plate 53.*

rrangement at Edgar Thompson Works.

Fig 1. *Plan.*

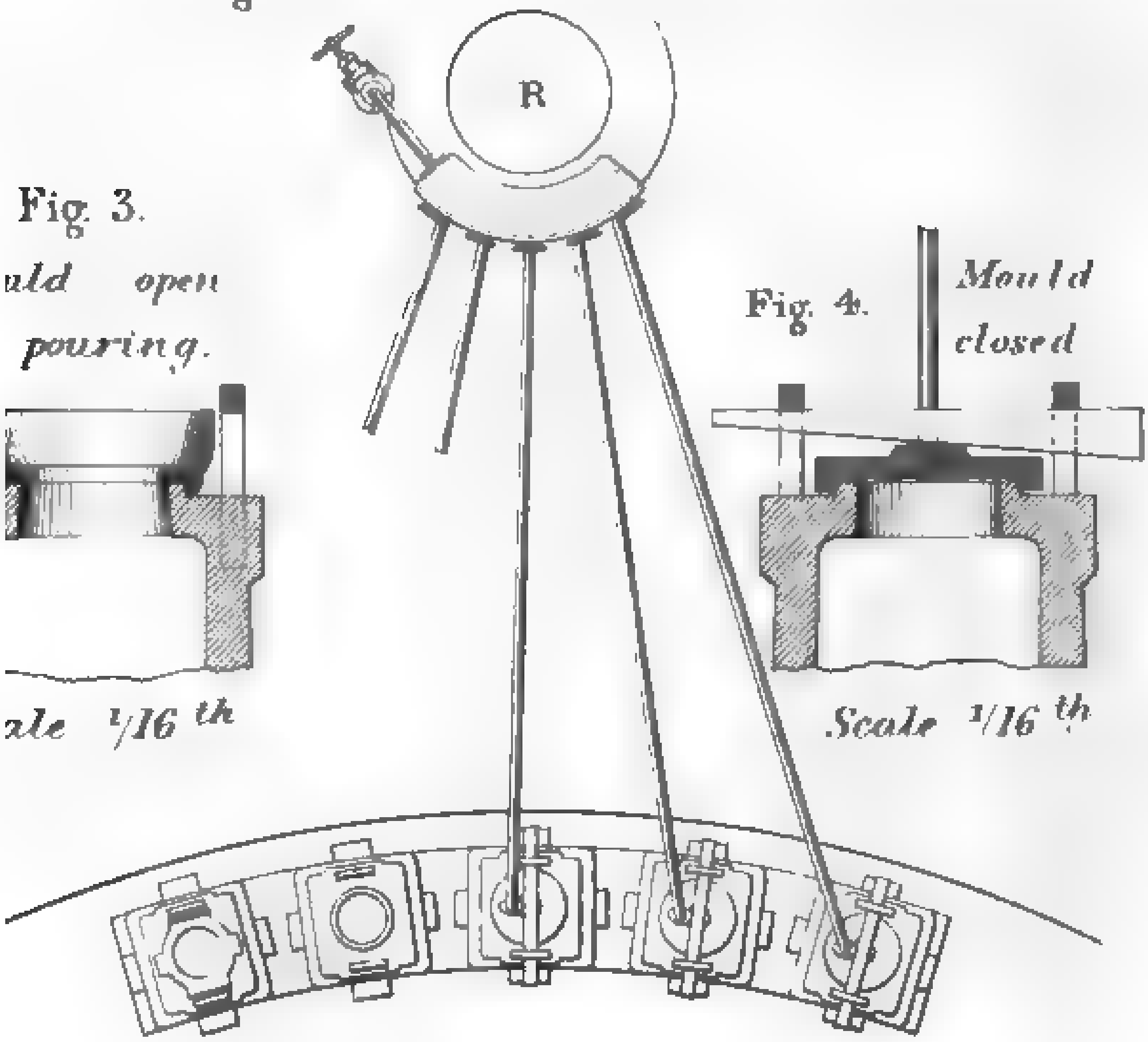
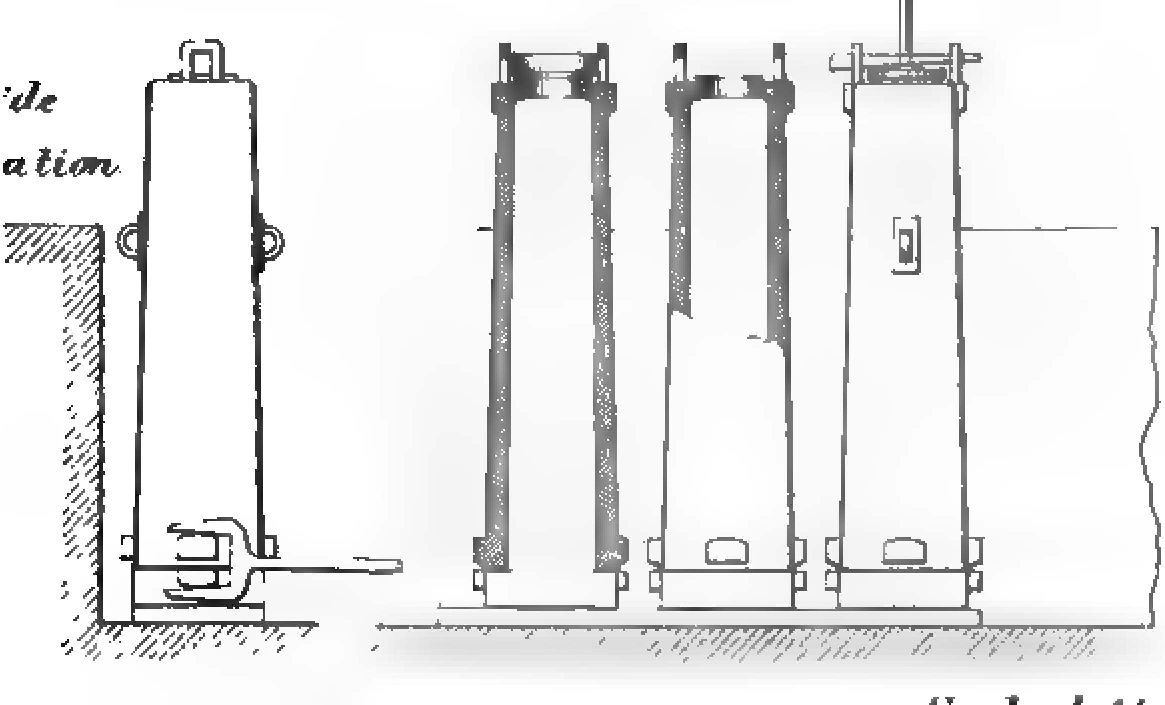


Fig 2 *Ingot Moulds.*



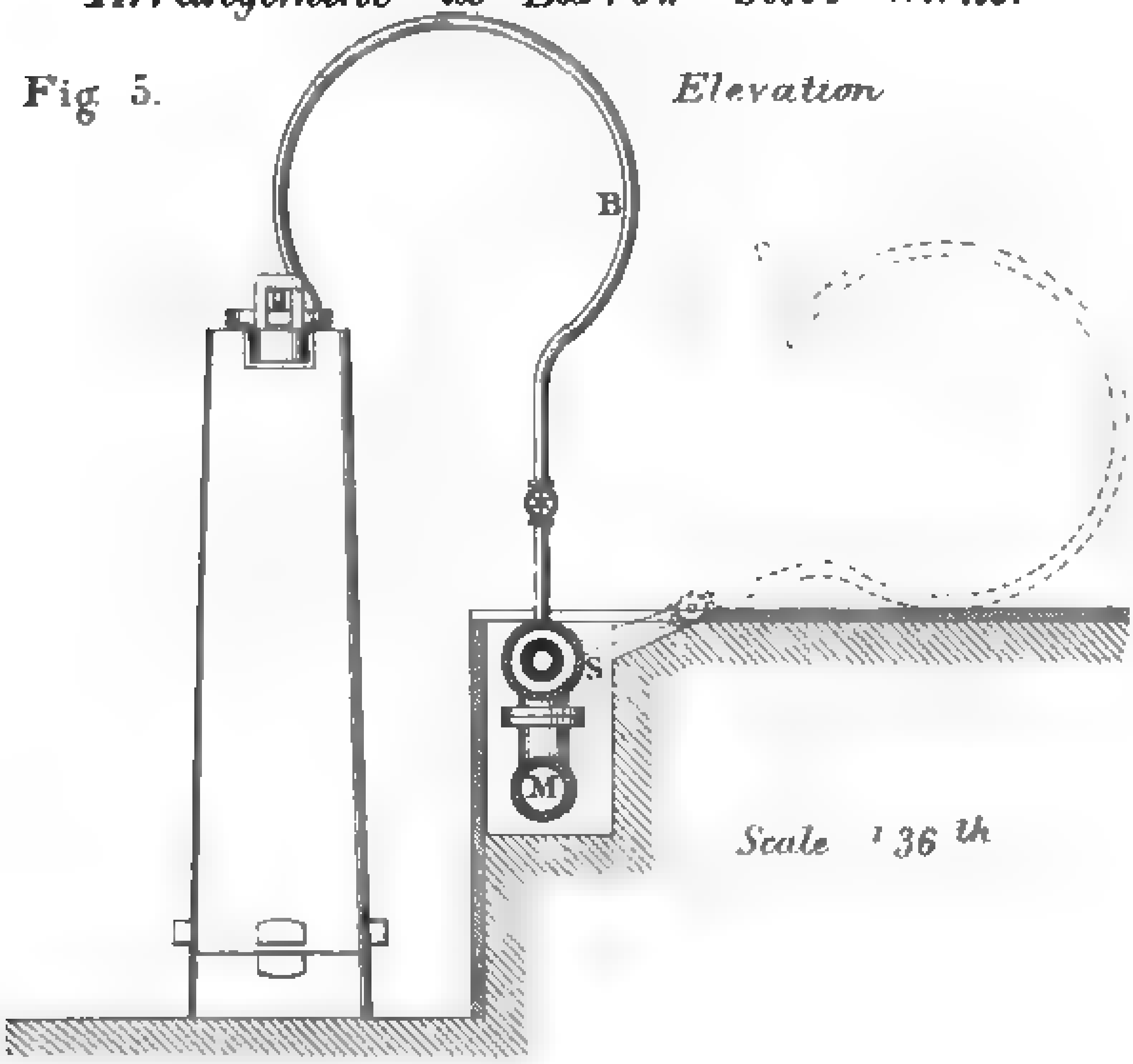
ceedings Inst. M E. 1880) *Scale 1/48*

[redacted]

STEEL-COMPRESSION BY STEAM. *Plate 54*

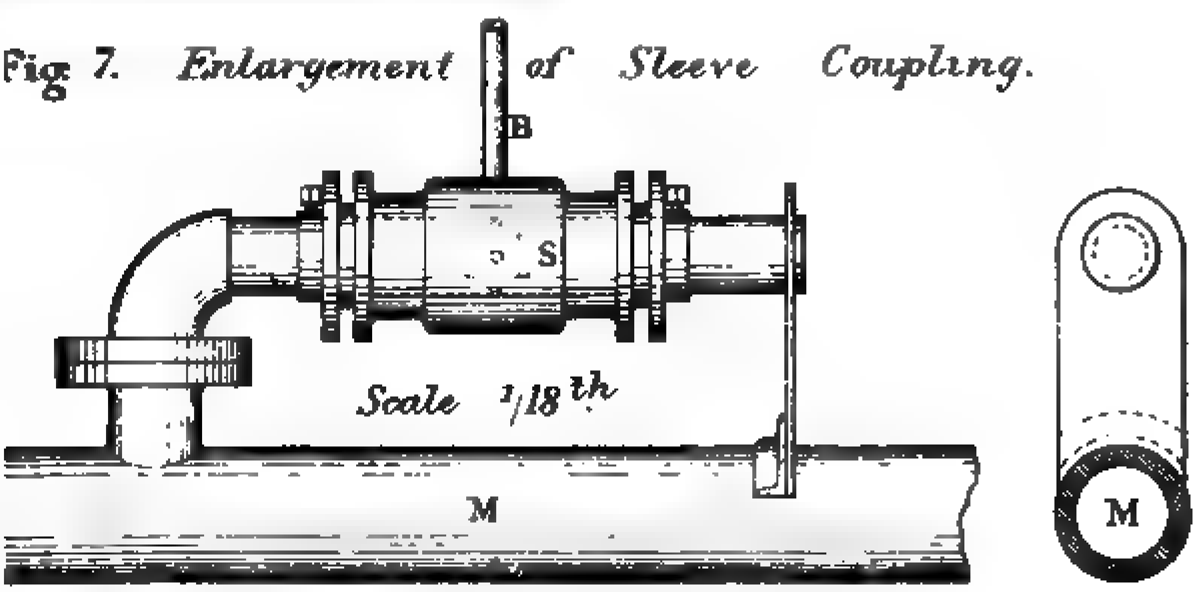
Arrangement at Barrow Steel Works.

Fig 5. *Elevation*



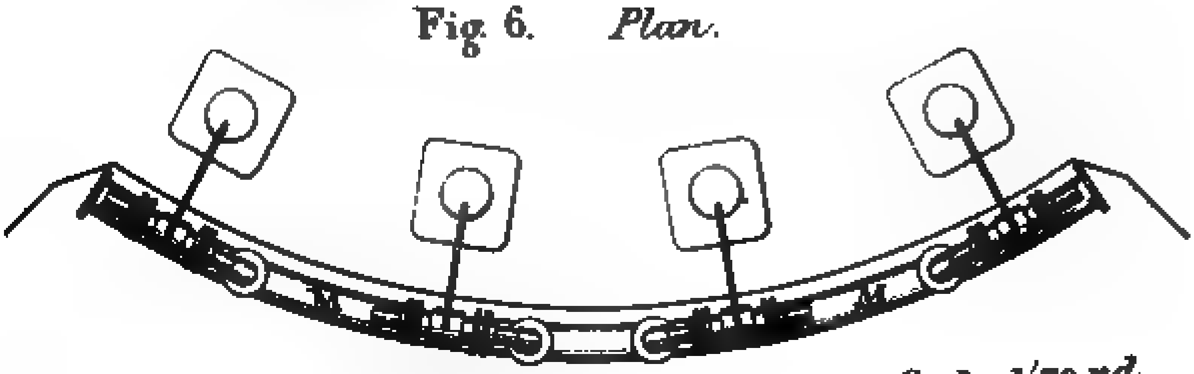
Scale 1/36th

Fig 7. *Enlargement of Sleeve Coupling.*



Scale 1/18th

Fig 6. *Plan.*



Scale 1/72nd

STEEL-COMPRESSION BY STEAM. *Plate 55.*

Joints for Ingot Moulds.

Fig. 9.

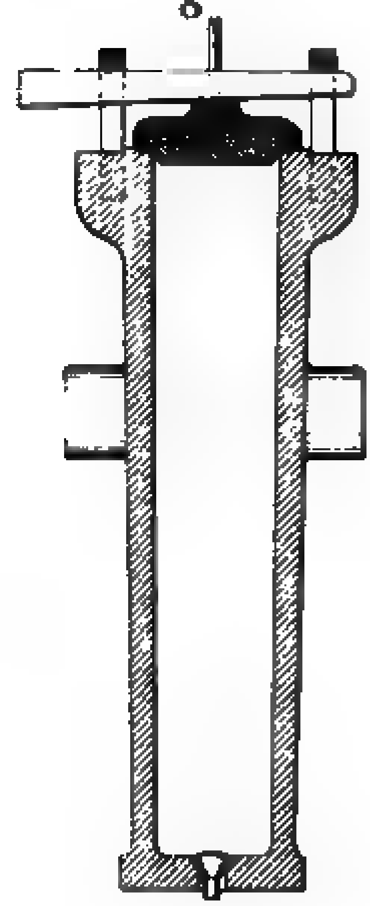


Fig. 8.
Full size.

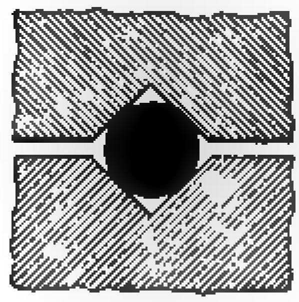


Fig. 10.

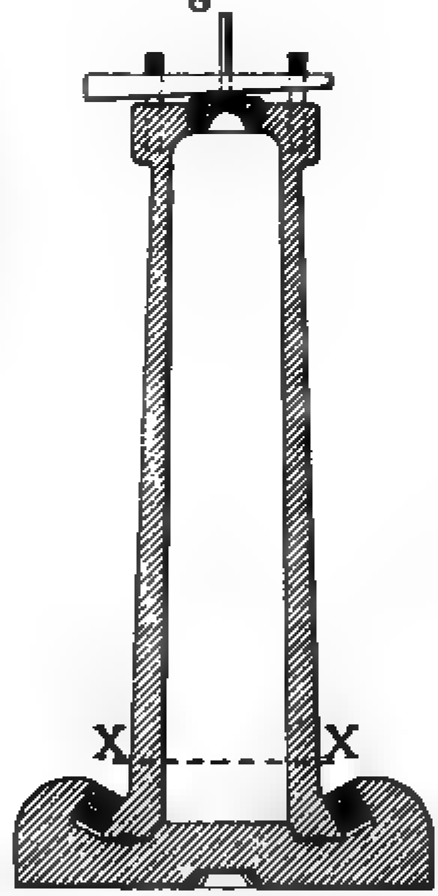


Fig. 12.

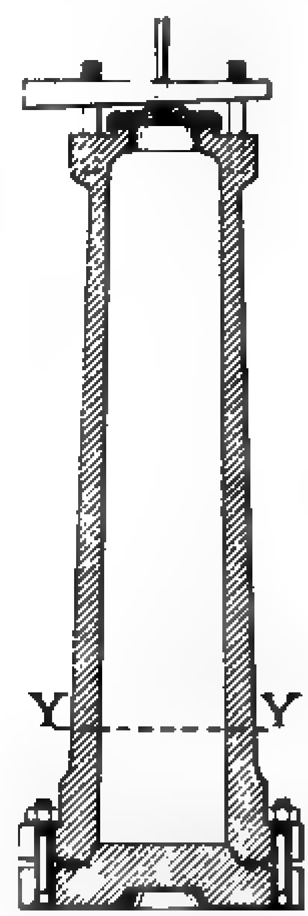


Fig. 11. *Section at* XX.

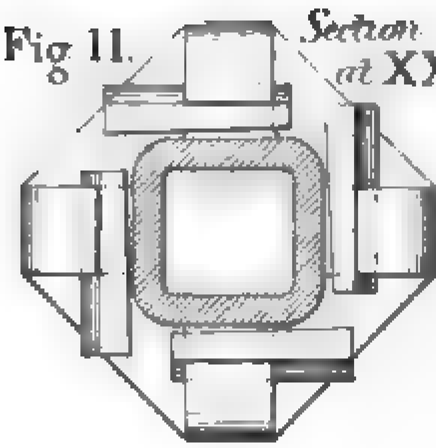


Fig. 14.
T Bolt enlarged.

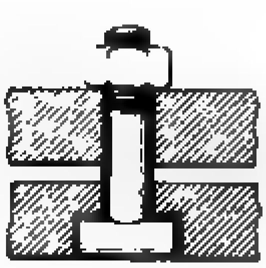


Fig. 13. *Section at* YY.

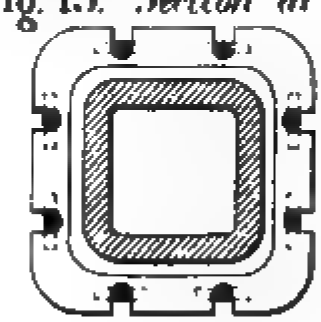
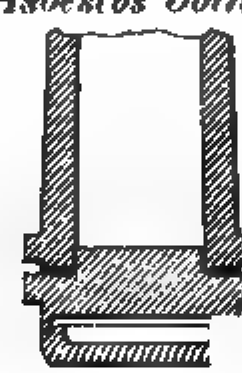


Fig. 15.
Asbestos Joint



(Proceedings Inst. M. E. 1880.)

STEEL COMPRESSION BY STEAM. *Plate 56.*

Sections of Ingots.

Fig. 16. Fig. 17. Fig. 18. Fig. 19.

Experimental Steel Boiler.

Fig. 20.

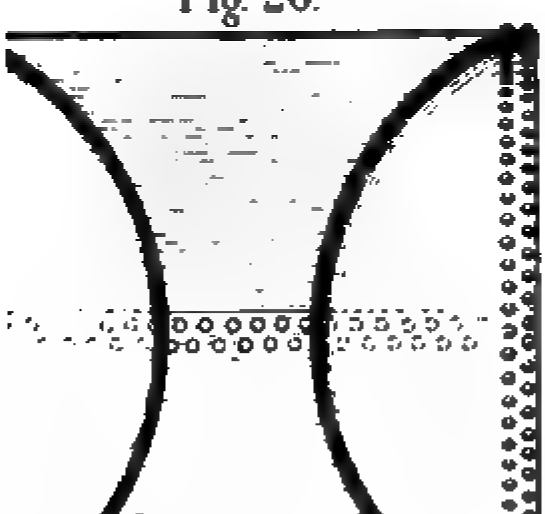
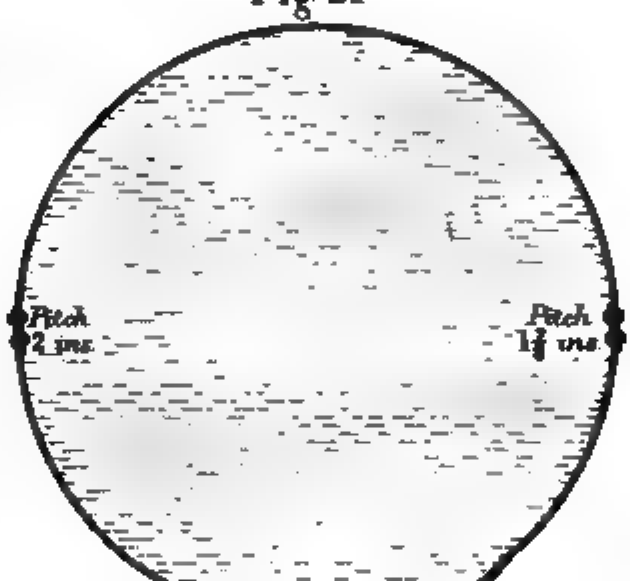


Fig 21



ceedings Inst M. E. 1880)

Scale 1/24th

Marine Engine with Joy's Gear.

Fig 1. Marine Engine with Link Gear.

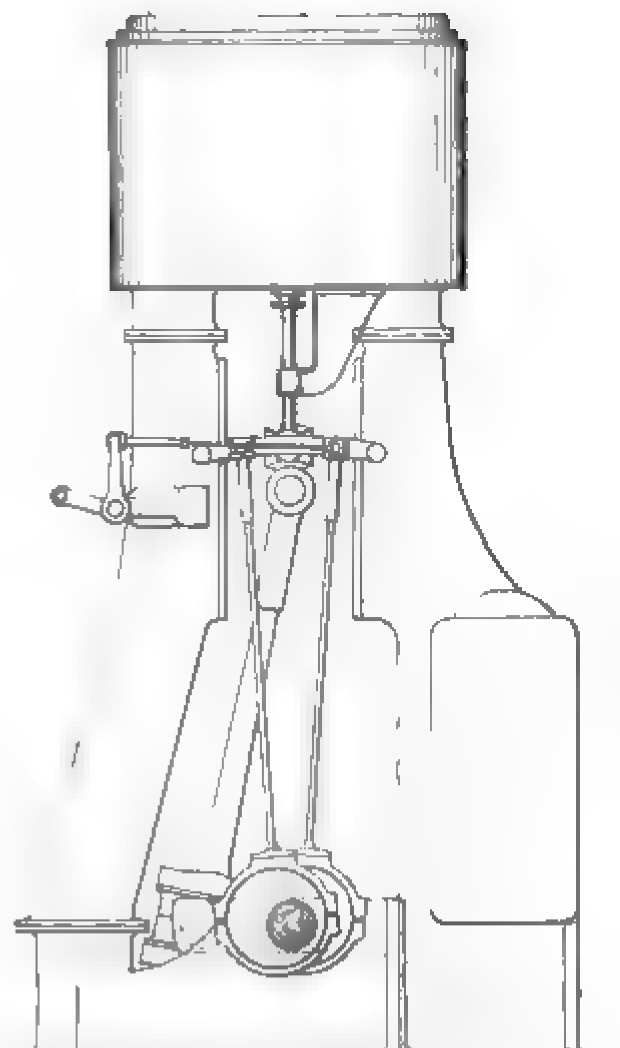


Fig 2. End Elevation

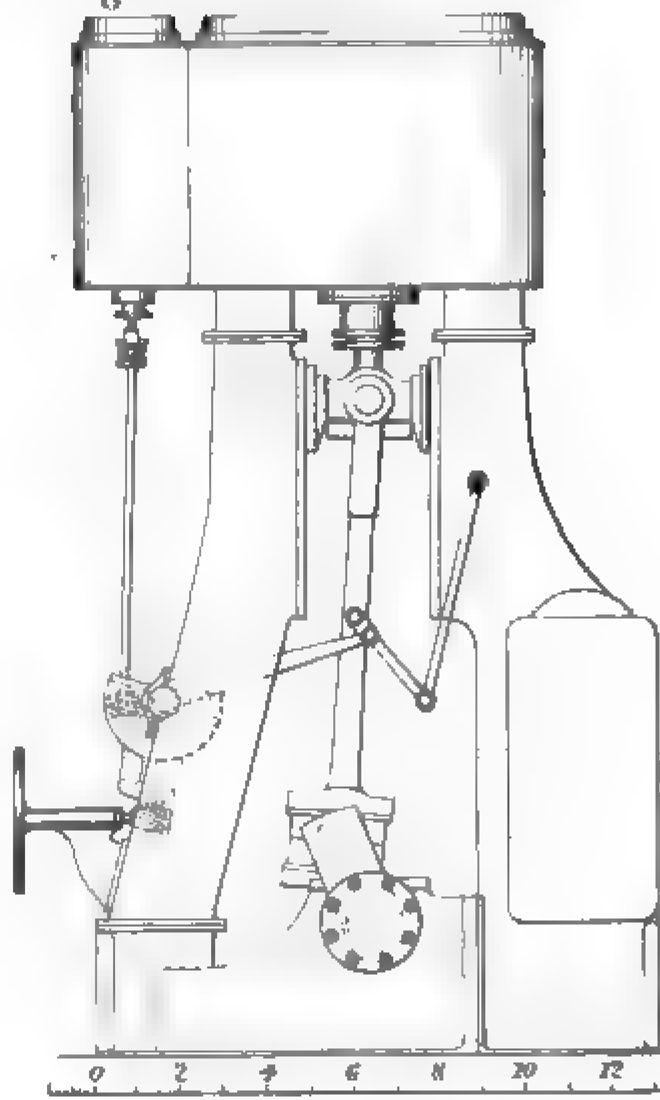
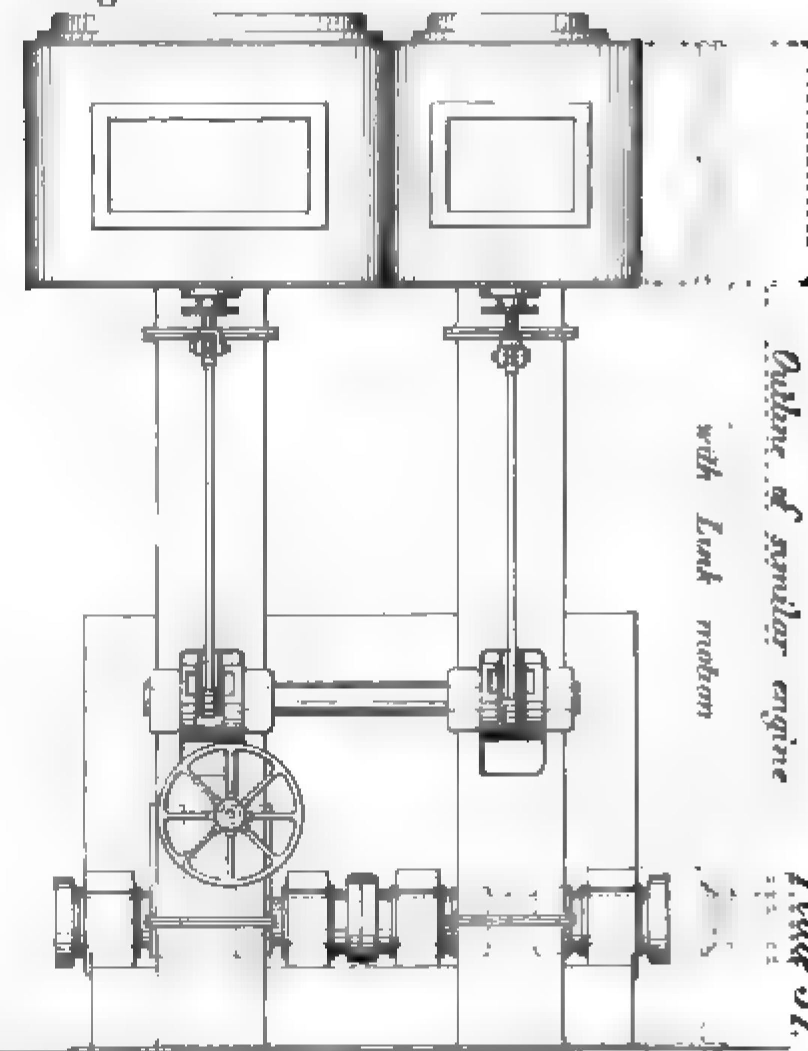


Fig 3 Front Elevation



Scale 1/80th

Plate 57.

Plate 58.

Horizontal Engine with Joy's Gear.

Fig. 4. Elevation.

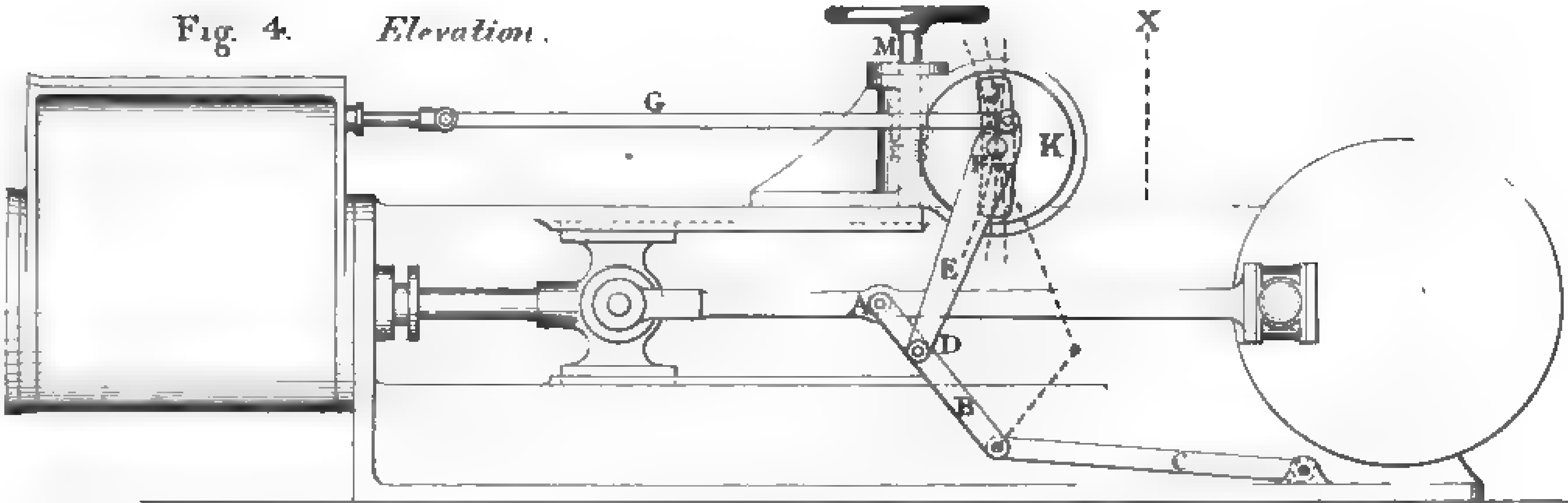


Fig 6. Section at XX.

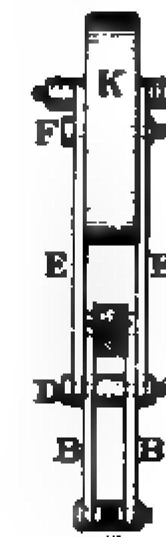
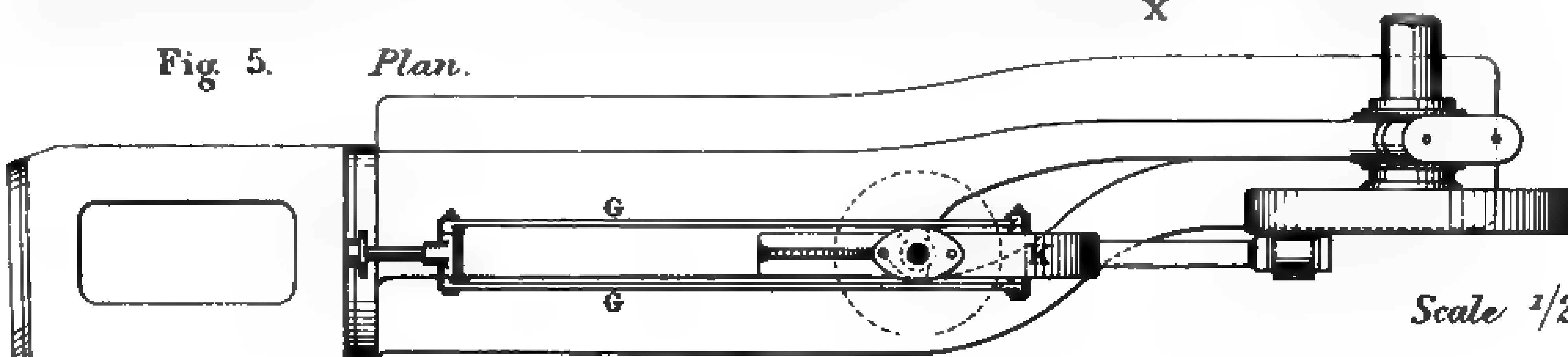


Fig. 5. Plan.



Scale 1/24 th

Fig. 7

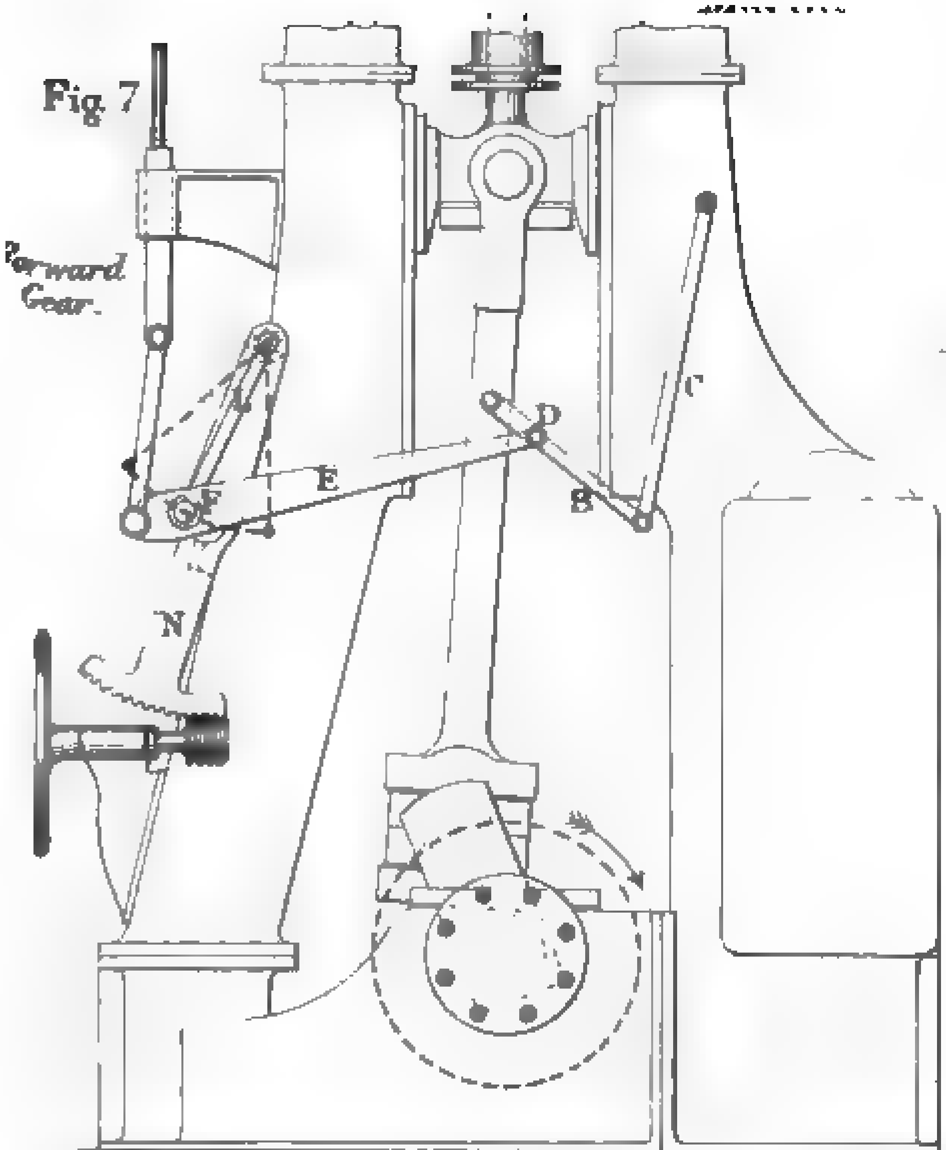


Fig. 15.
Path of Crank.

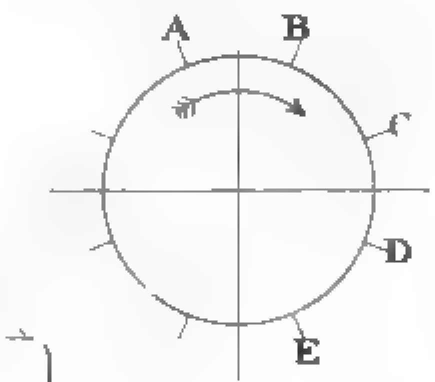


Fig. 8.

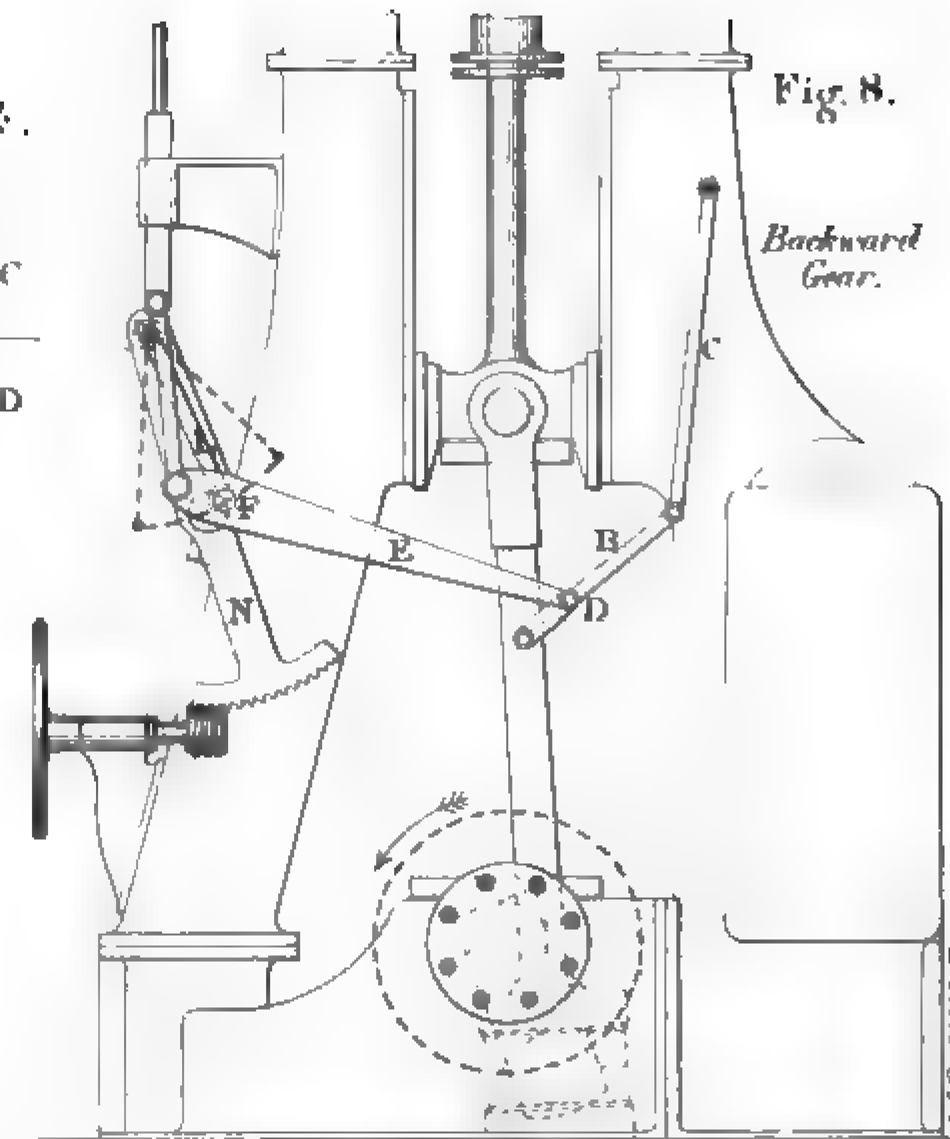


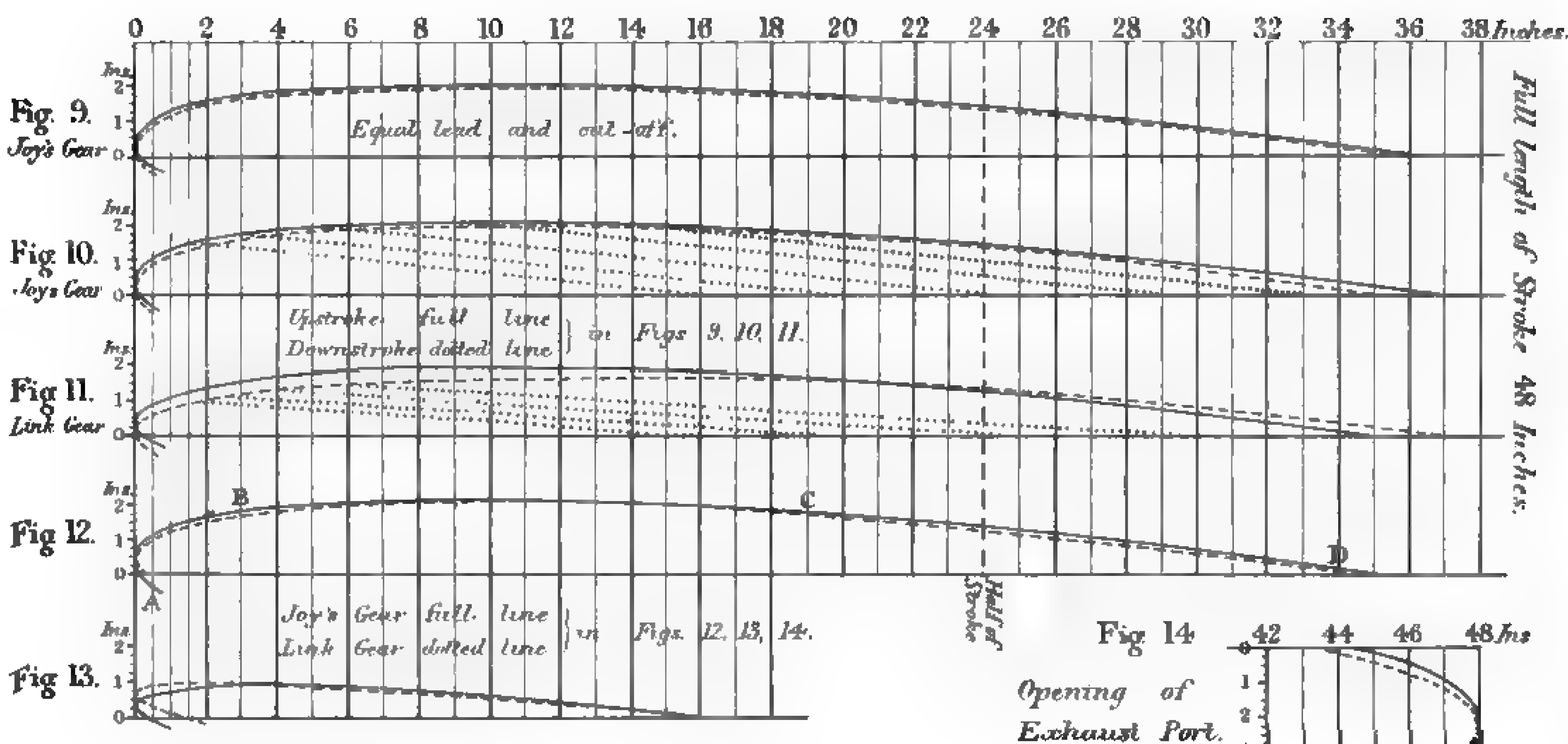
Plate 59.

(Proceedings Inst M E 1880.)

Inches 12 6 0 2 4 6 8 10 12 Feet

Scale 1/50th

Diagrams showing Opening of Steam Ports.



(Proceedings Inst M. E. 1880.)

Scale 1/6 th

Fig 16. *London and North Western Engine with Joy's Gear.*

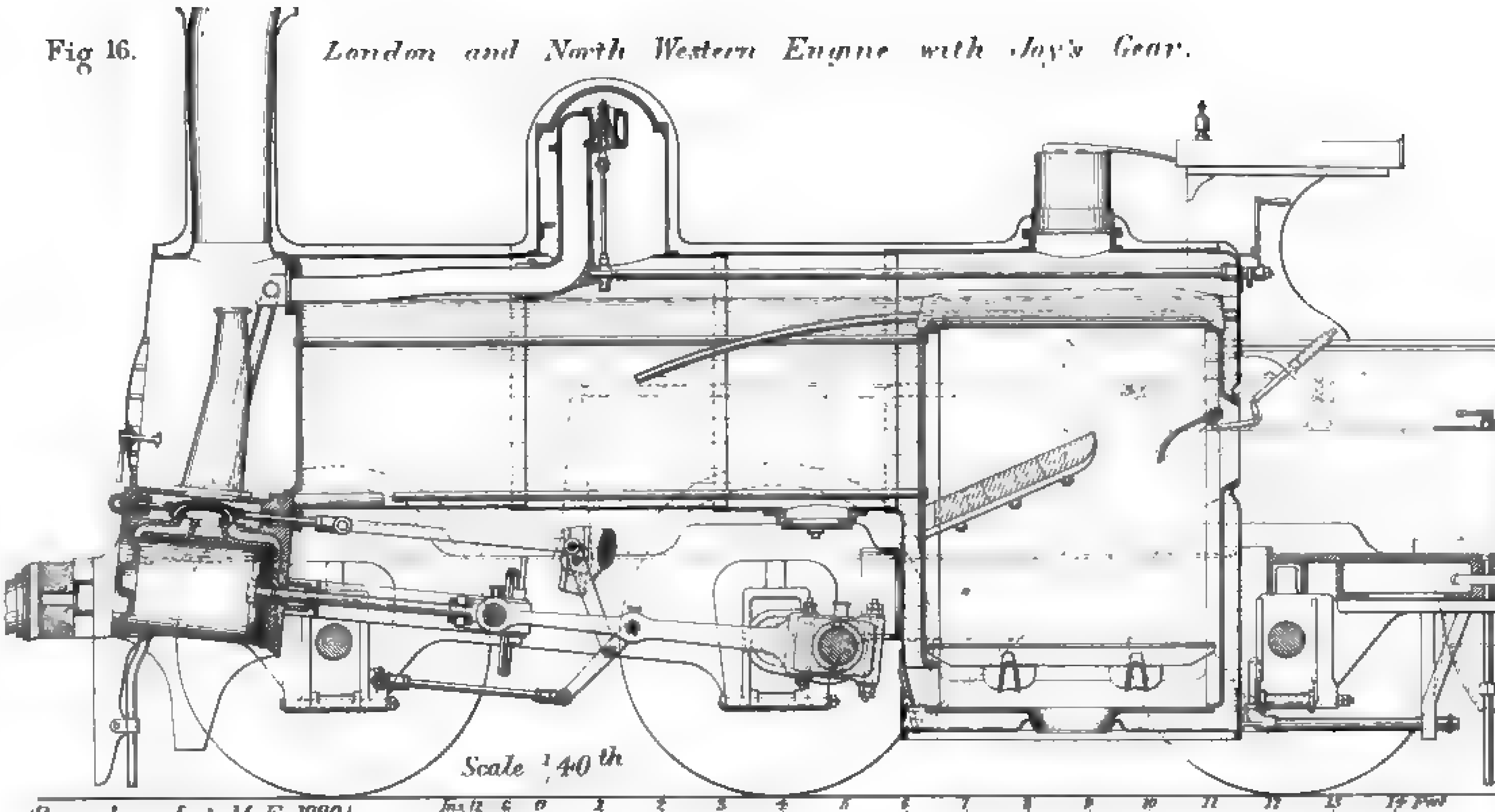
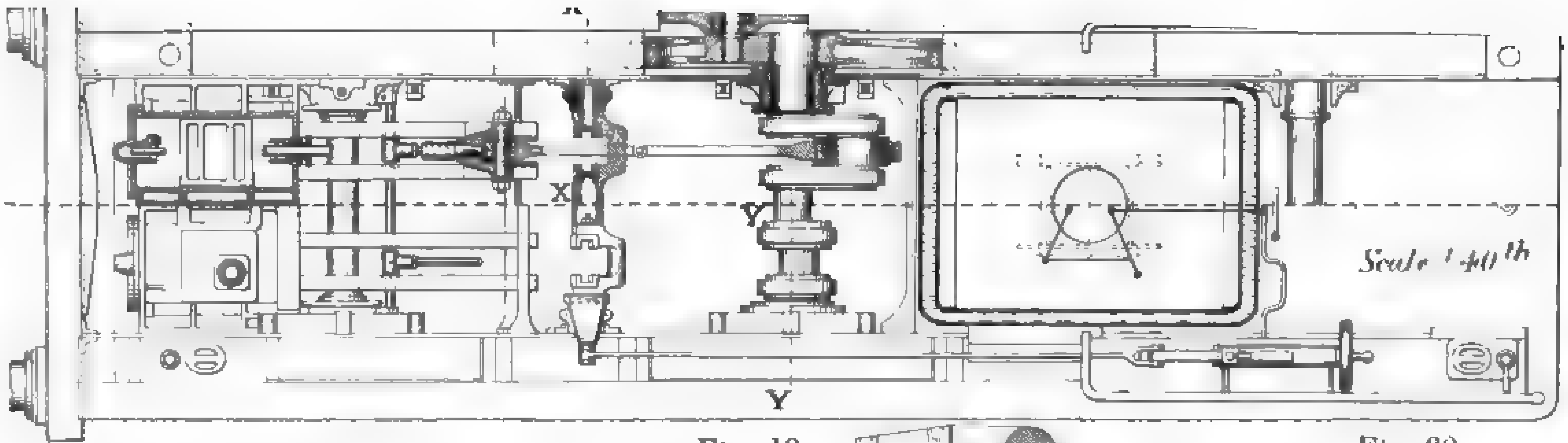


Plate 61.

(Proceedings Inst. M E 1880)

Plate 62



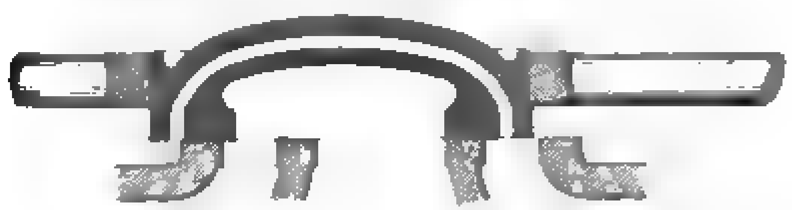


Fig 18
Section of Truck Valve.

Scale 1/10th

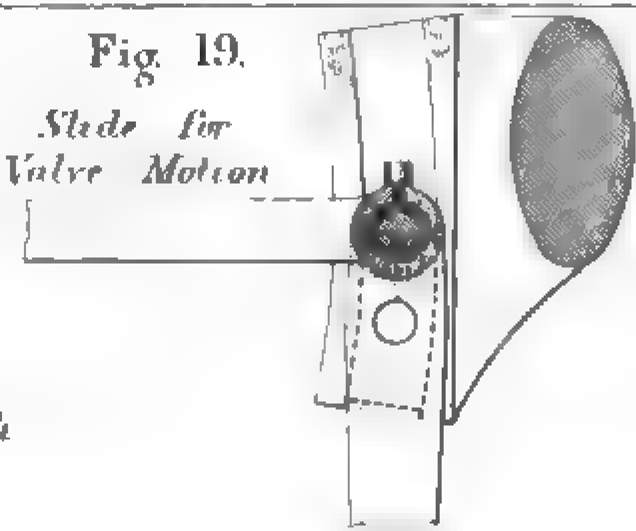


Fig. 19.
Slide for Valve Motion

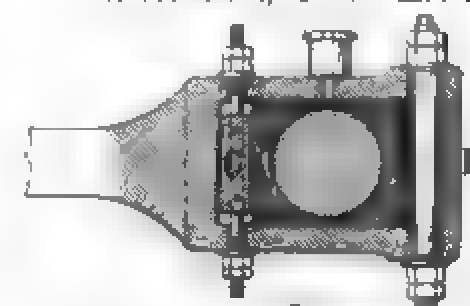


Fig. 20.
Connecting-Rod End

Scale 1/20th

…ceedings Inst M E 1880)

VALVE GEAR.

London and North Western Goods Engine, with Joy's Gear.

Fig. 21. *Valve Gear.*

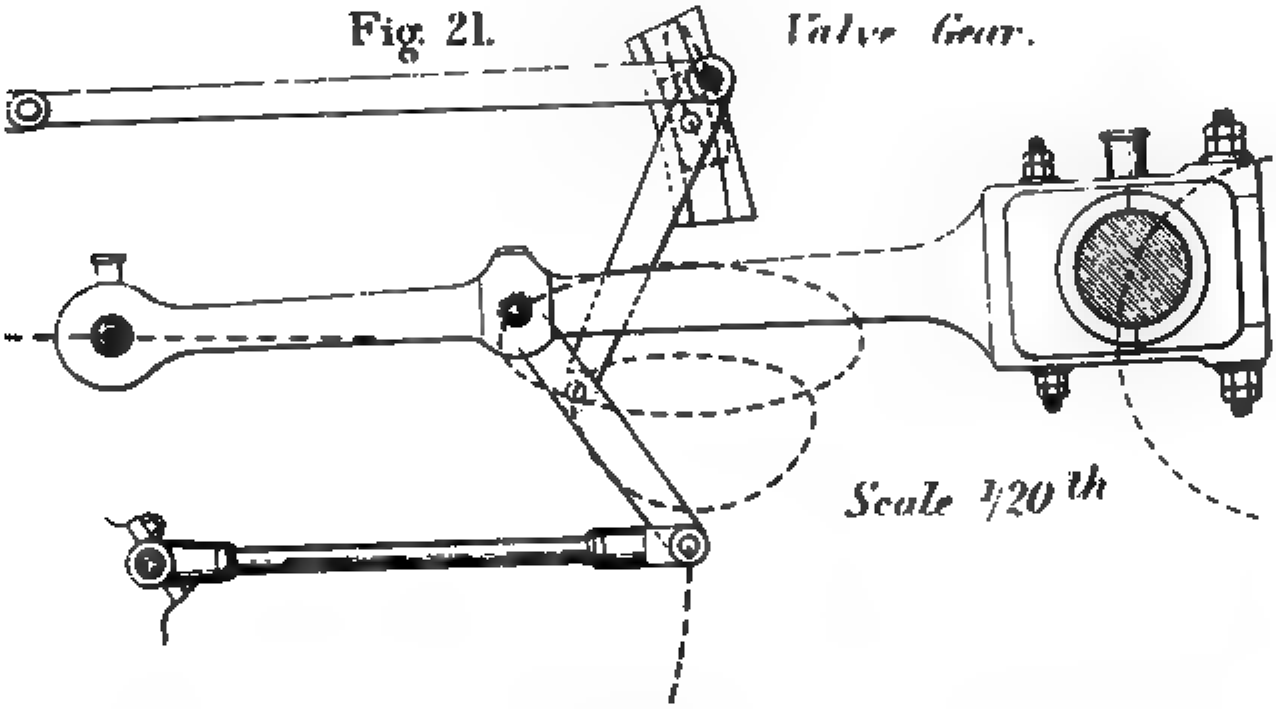
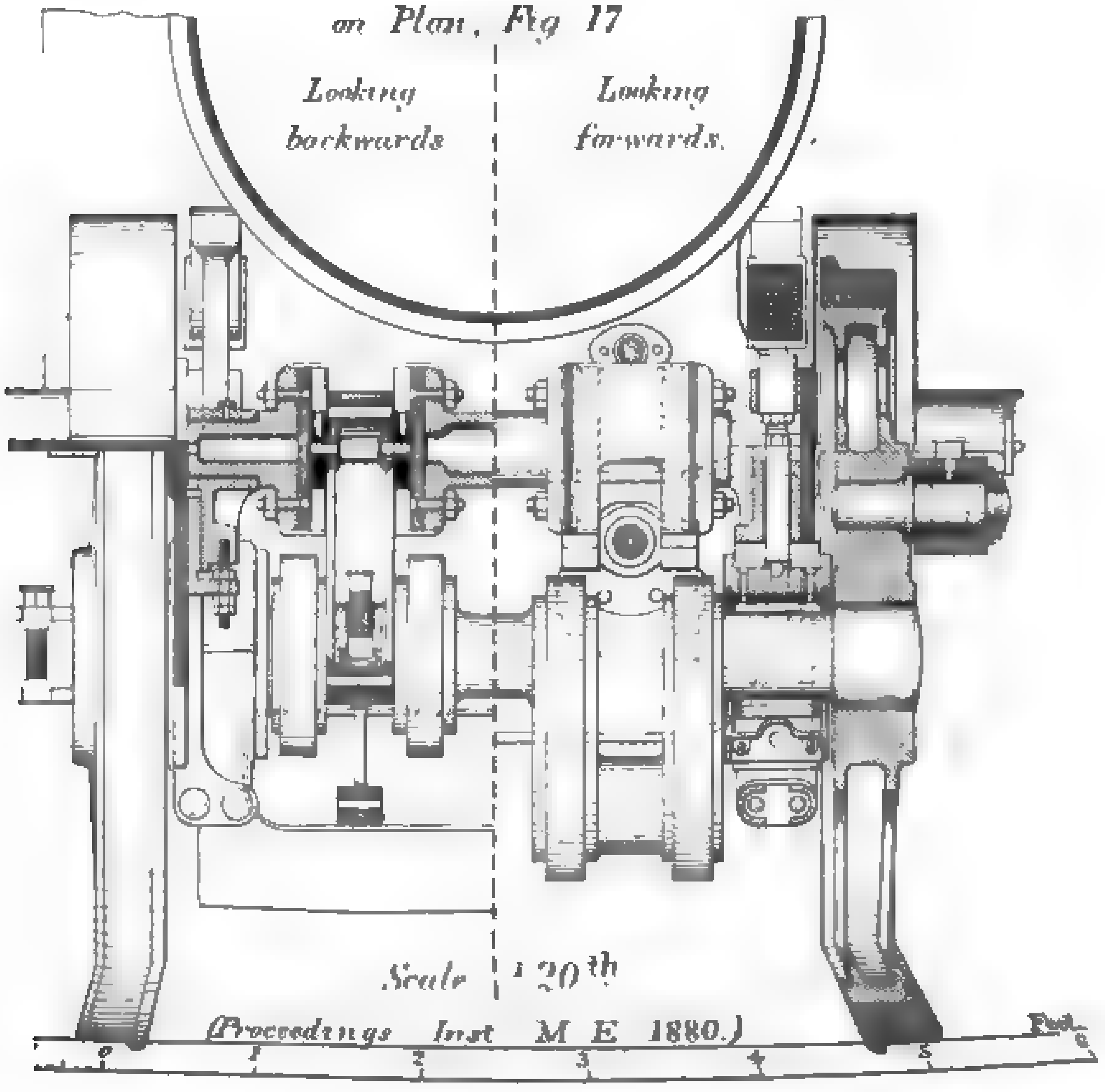


Fig. 22. *Half Cross Sections along XX and YY on Plan, Fig 17*



VALVE GEAR. *Plate 64.*

London and North Western Goods Engine, with Joy's Gear.

Fig. 23. *Low Speeds.*

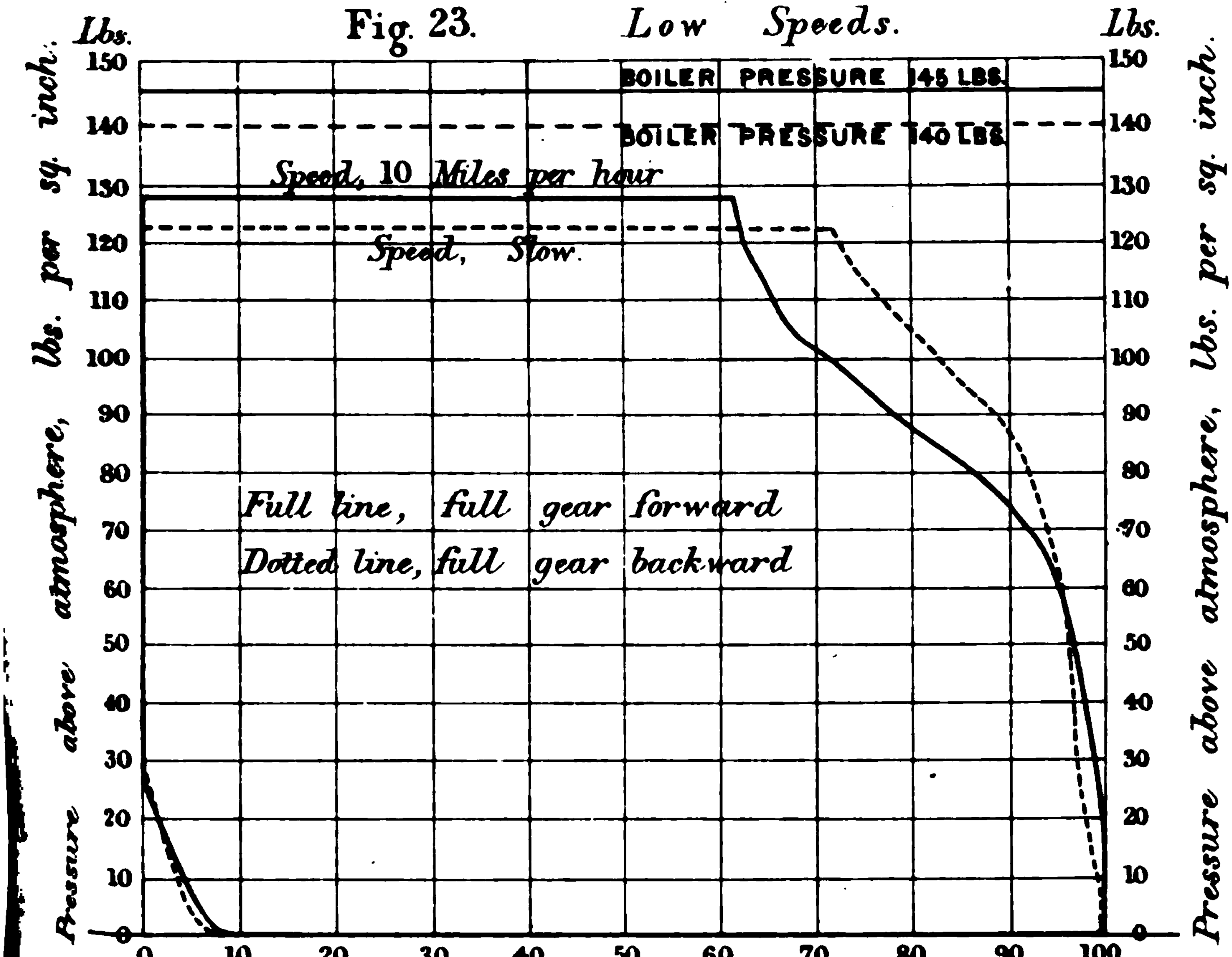
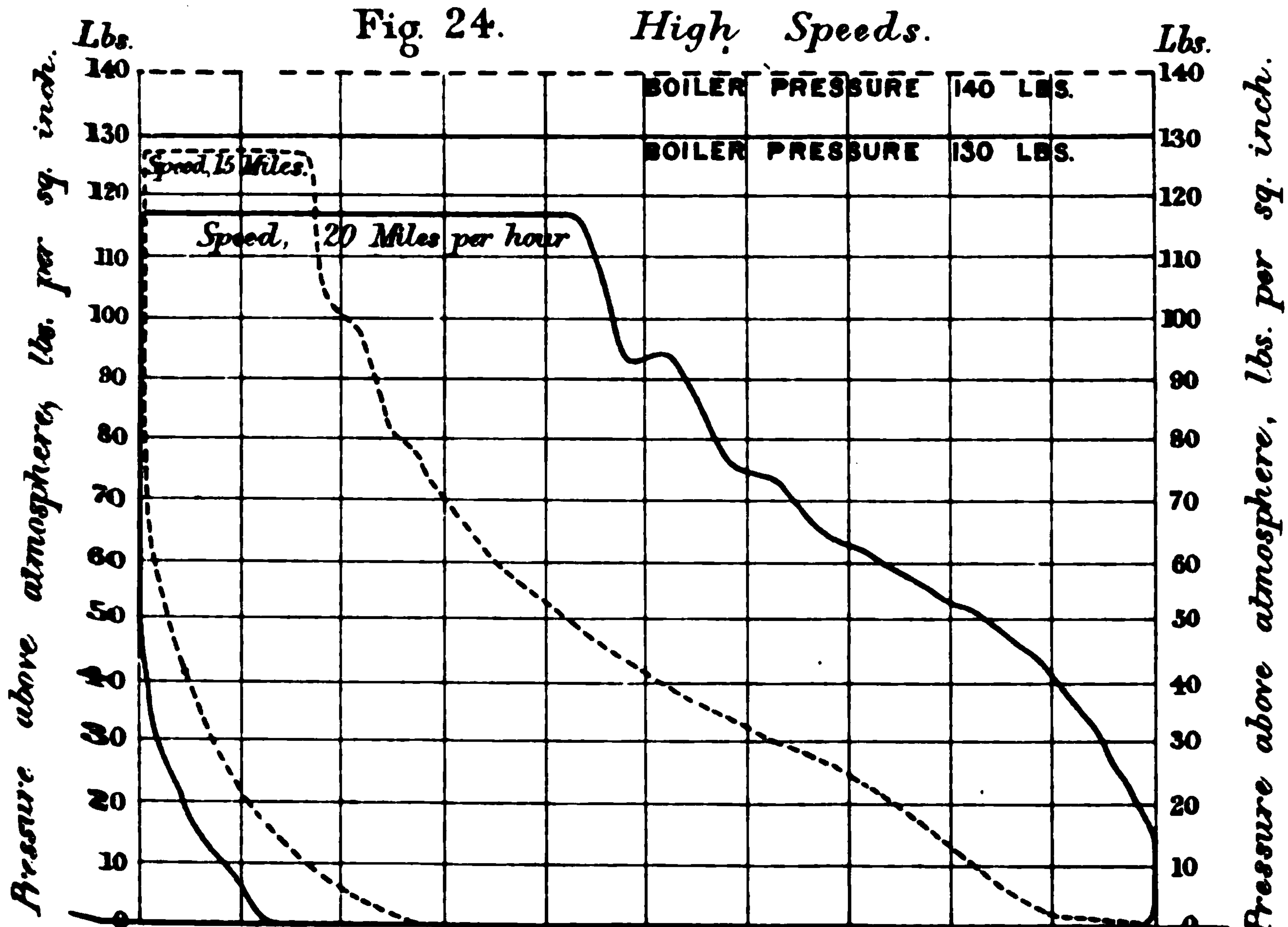


Fig. 24. *High Speeds.*



VALVE GEAR. *Plate 65.*

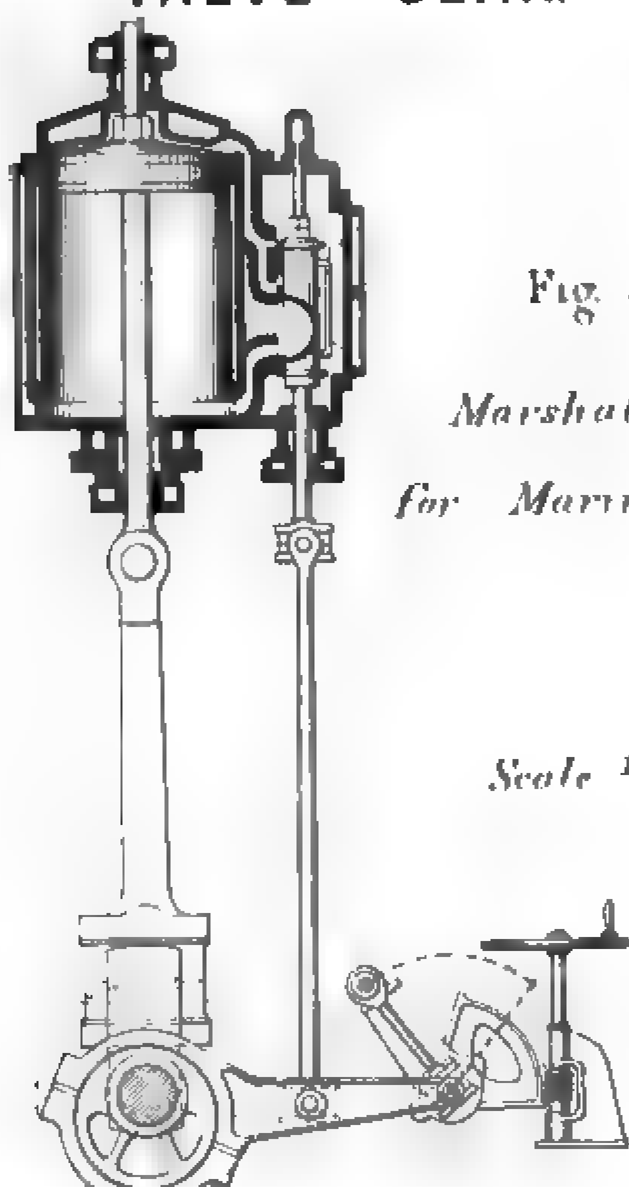


Fig. 25

Marshall's Gear for Marine Engines.

Scale 1/64th

Motion Enlarged.

Fig. 26. *Elevation*

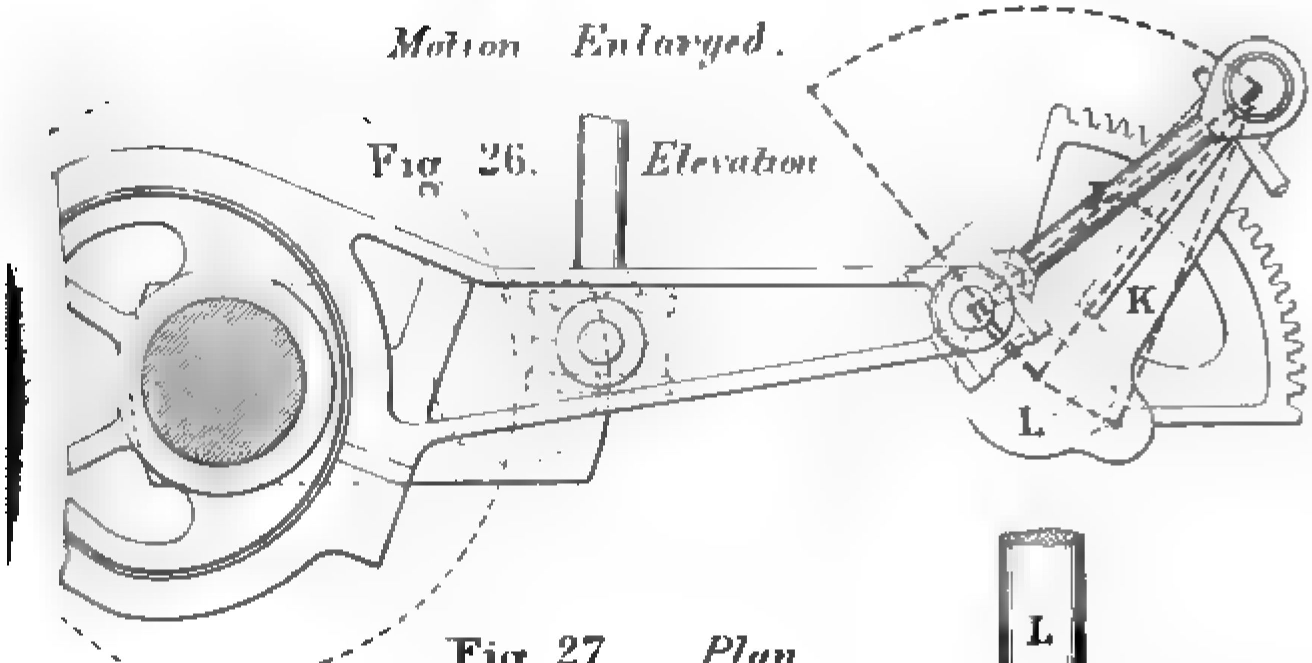
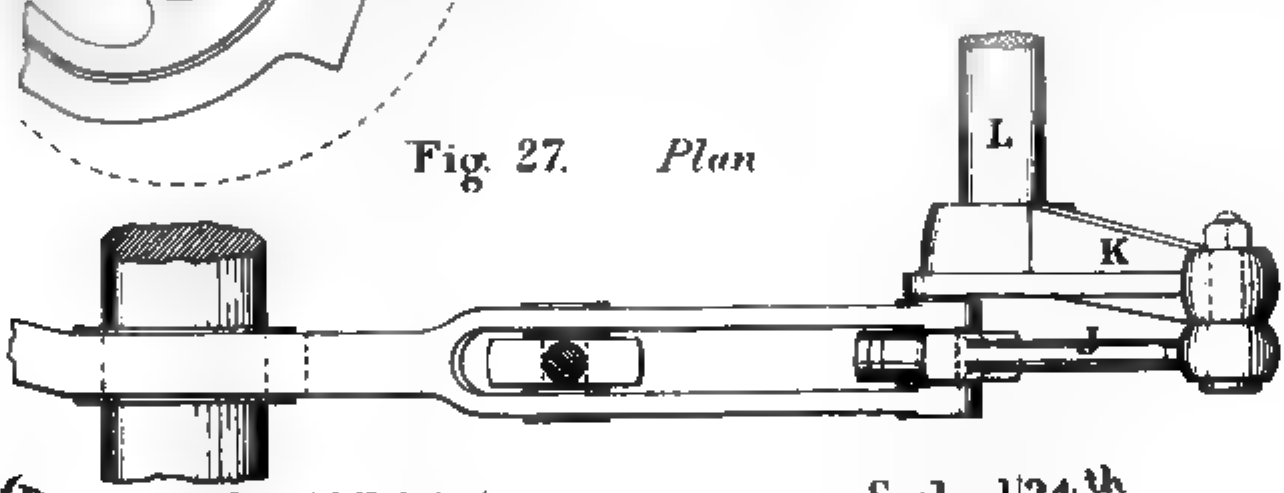


Fig. 27. *Plan*



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Scale 1/24th

VALVE GEAR. *Plate 66.*

Diagrams from S.S. "Osmanli," with Marshall's Gear.

Nº of Grade	1	2	3	4	5	6
Revolutions per min.	57	53	50	[illegible]	[illegible]	35
Ind. H.P. of H.P. Cyl.	715	599	513	395	277	190
. . . *L.P. Cyl.*	694	542	486	375	270	199
. . *Total*	1409	1141	999	770	547	389

Fig. 28. *High-Pressure Cylinder.*

Diam 35 ins. Stroke 48 ins.

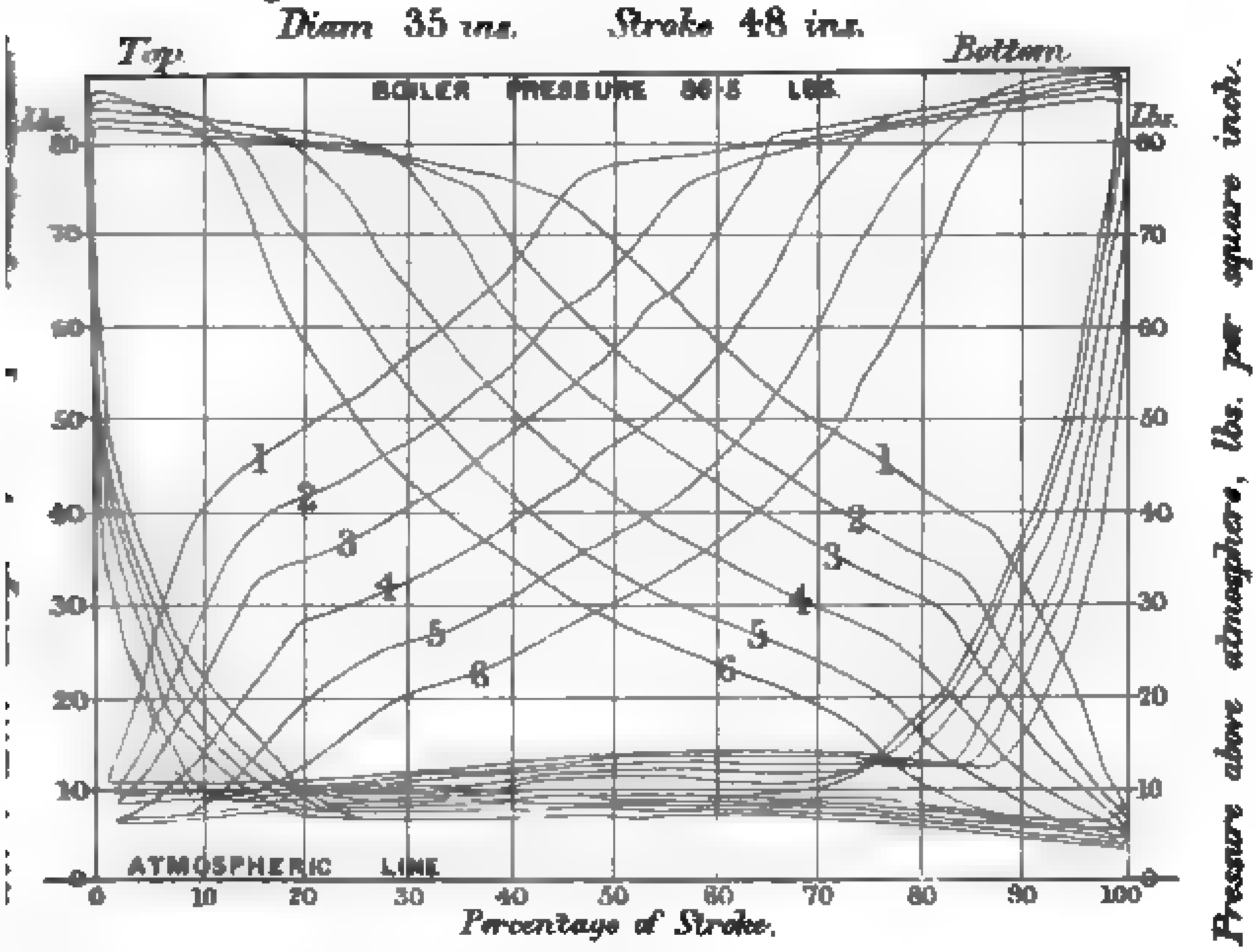
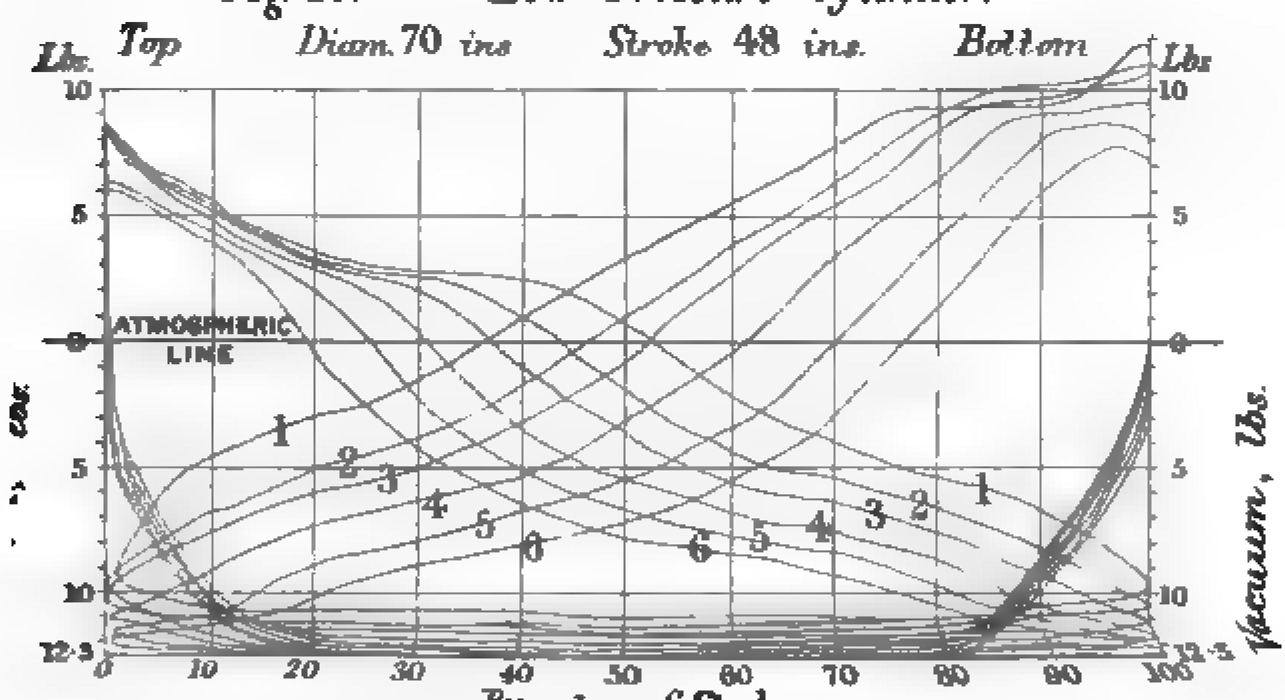


Fig. 29. *Low-Pressure Cylinder.*



(Proceedings Inst. M. E. 1880)

Institution of Mechanical Engineers.

10 Victoria Chambers, London, S.W.

January, 1881.

Dear Sir,

Since the publication of the last number of Proceedings, 'or August 1880, an error has been pointed out to me in the 'ertical scale of the high-pressure diagrams, Plate 66, by which he difference in pressure between the boiler and cylinder is nade to appear very much greater than it really was. To ;orrect this mistake the plate has been re-drawn, and a copy of .he corrected plate is sent you herewith, having a gummed edge next the hinge. Kindly have this inserted, according to lirections below, in the copy of Proceedings which was sent to you.

Apologising for the error, and for the trouble thus occasioned to you, I remain,

Yours truly,

WALTER R. BROWNE,

Secretary.

DIRECTIONS.—Moisten the gummed edge of the new Plate 66. Place the new Plate 66 *in front of* the old Plate 66, and press them ogether, so that they may adhere by the gum at the edge. Leave the gum to dry, and finally cut off the old plate along the edge of the gum, eaving the new plate in its place.

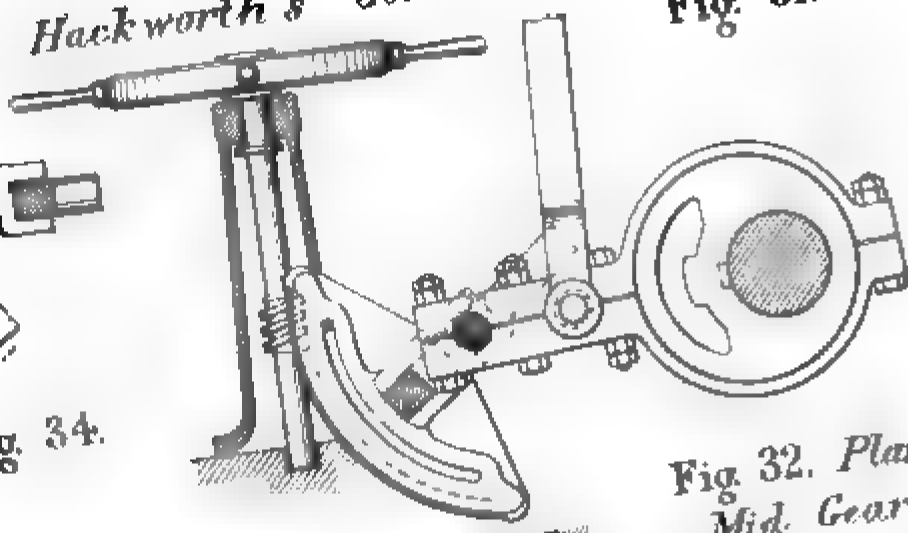
[redacted]

Plate 68.

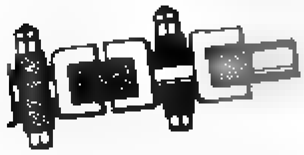
VALVE GEAR.

Hackworth's Gear.

Fig. 31.



33.



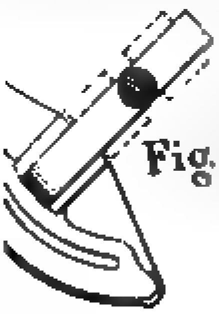
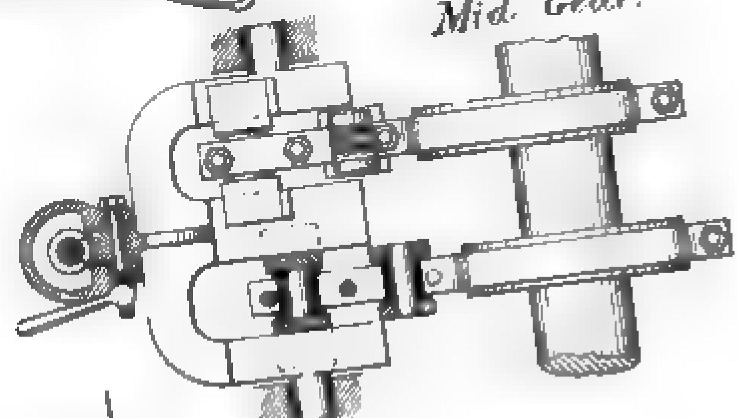


Fig. 34.

Fig. 32. Plan. Mid Gear.



Valve Rods

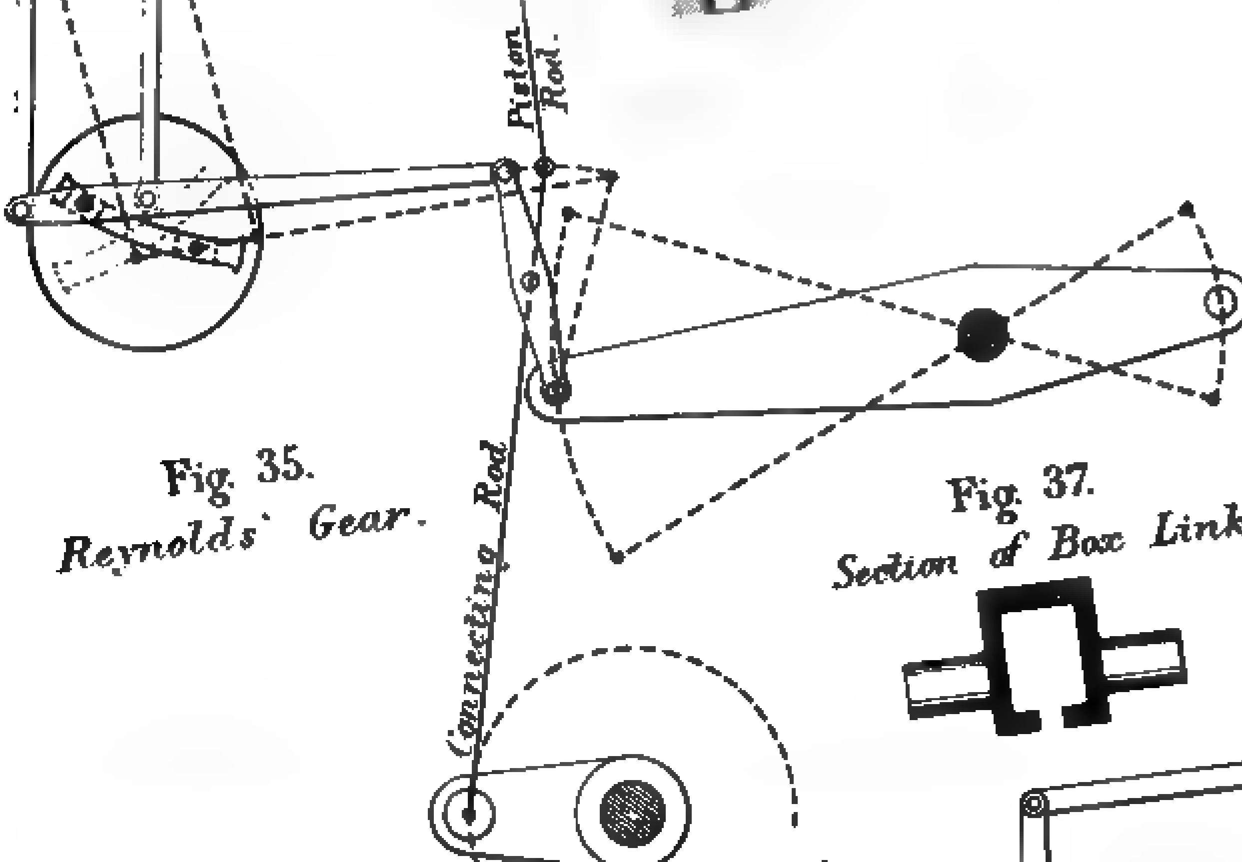


Fig. 35. Reynolds' Gear.

Fig. 37. Section of Box Link.

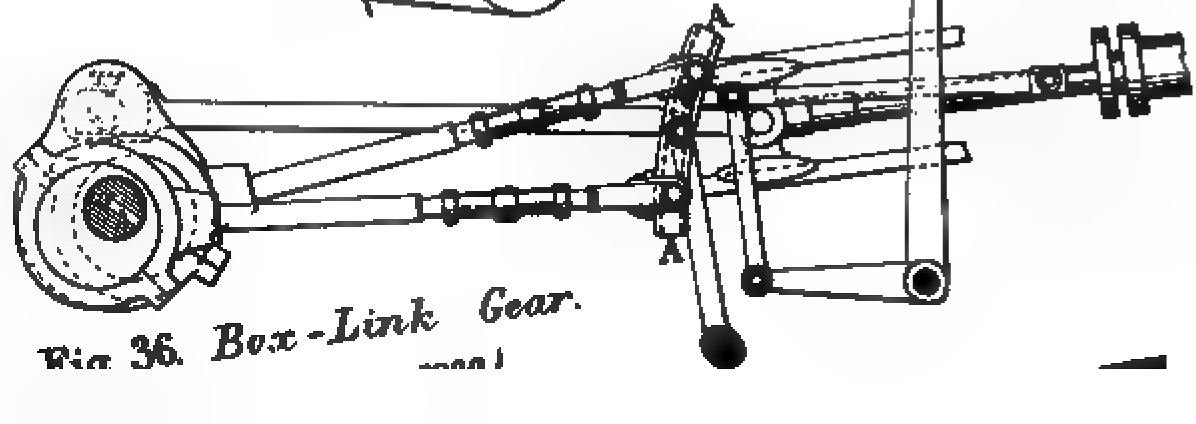


Fig. 36. Box-Link Gear.

VALVE GEAR. *Plate 69.*

Fig. 38 *Walschaert's Gear.*

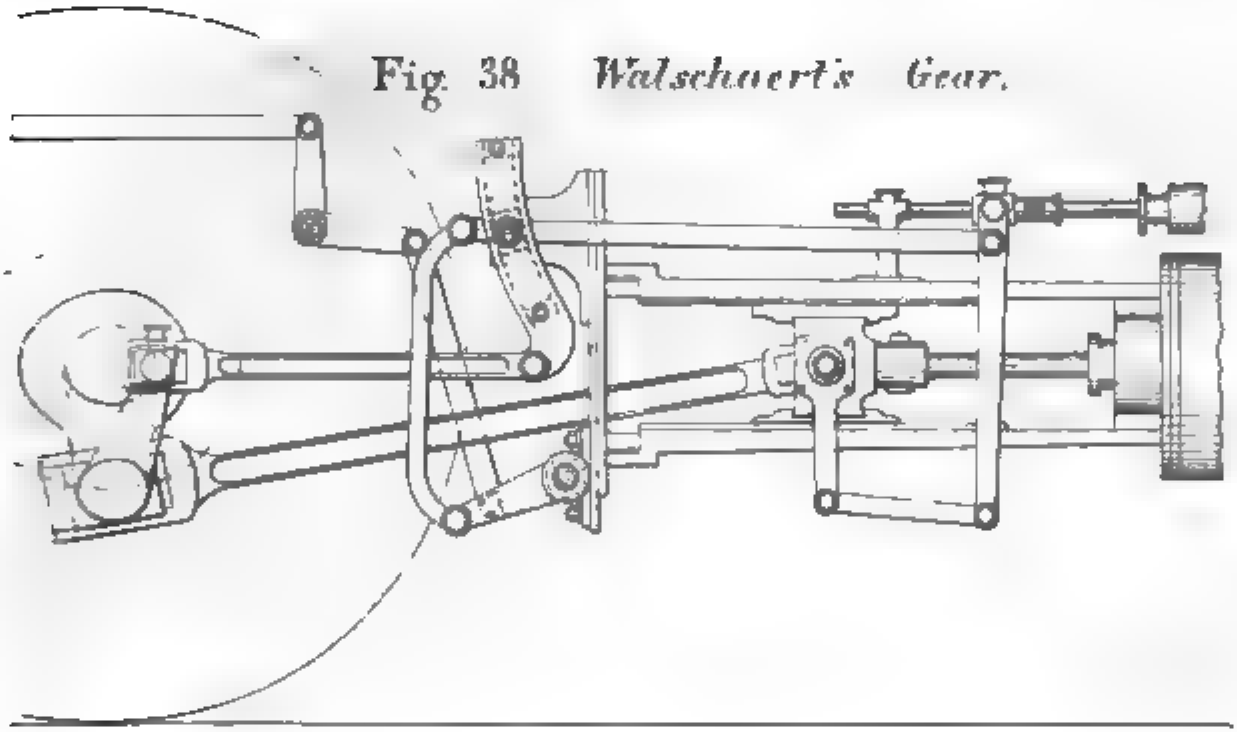


Fig. 39 *Brown's Gear.*

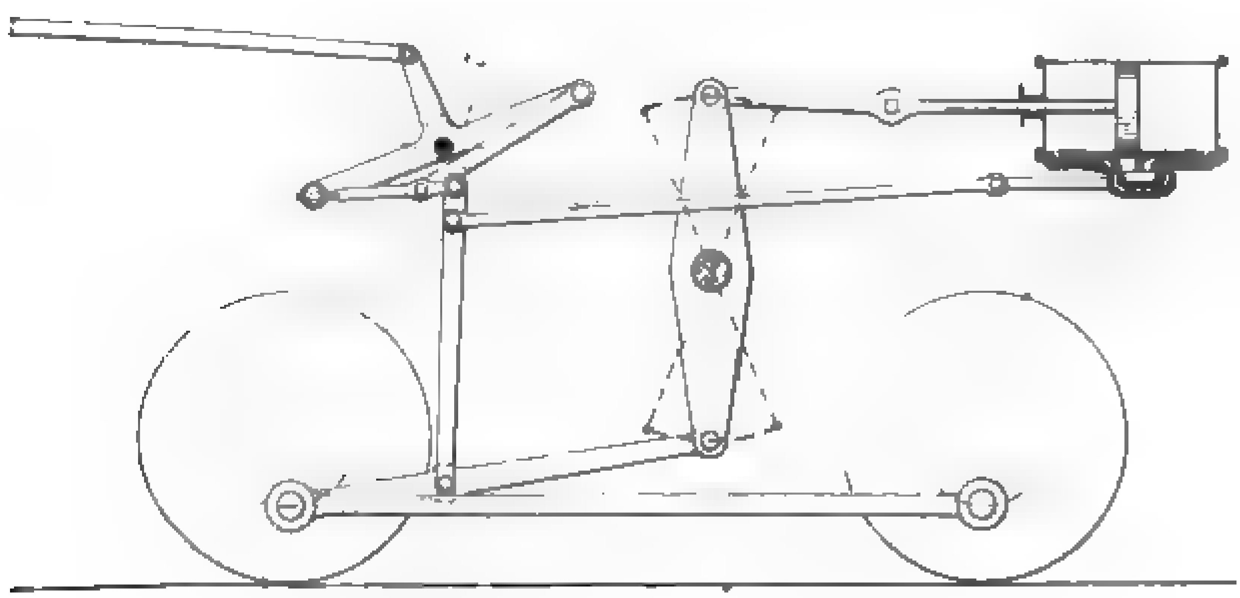
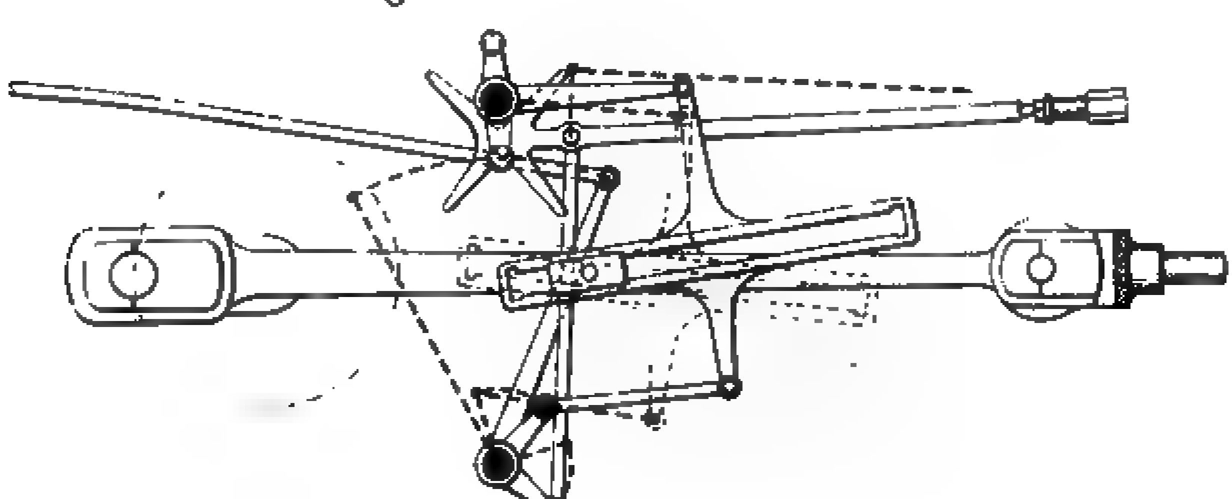


Fig. 40 *Hawthorn's Gear.*

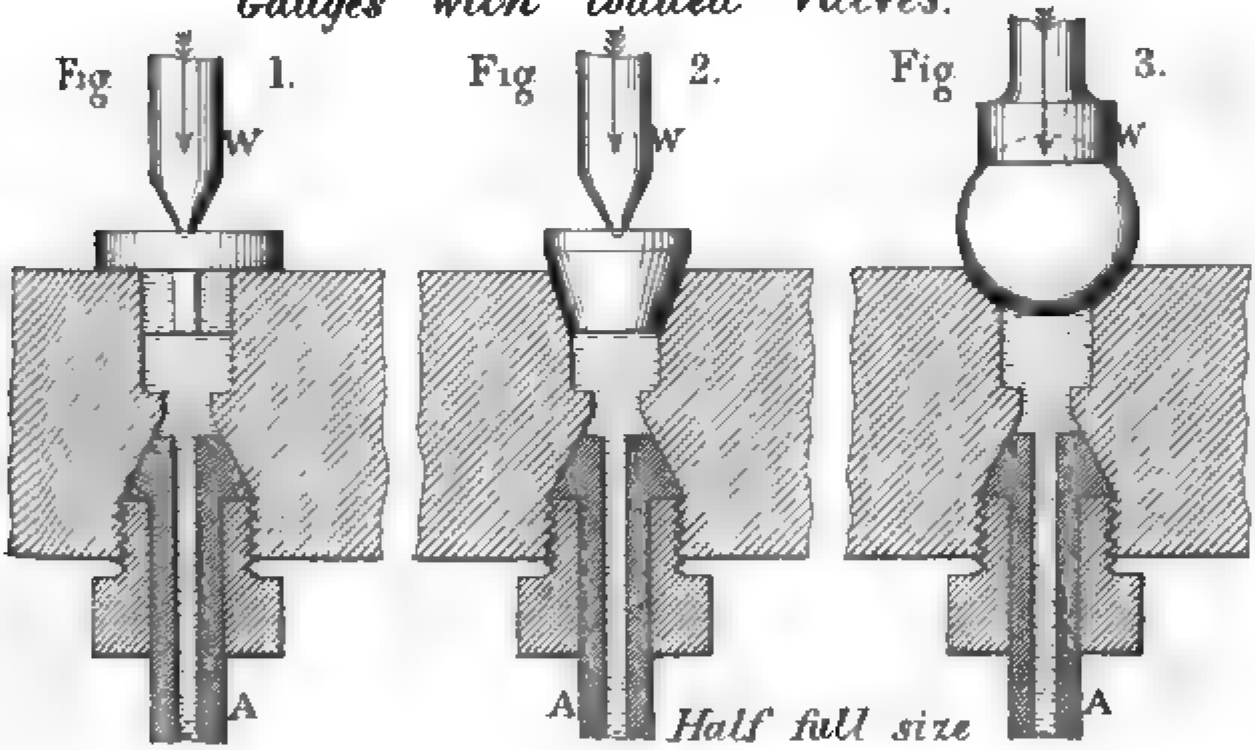


(Proceedings Inst. M.E. 1880.)

[redacted]

STANDARD GAUGE. *Plate 70.*

Gauges with loaded Valves.



Half full size

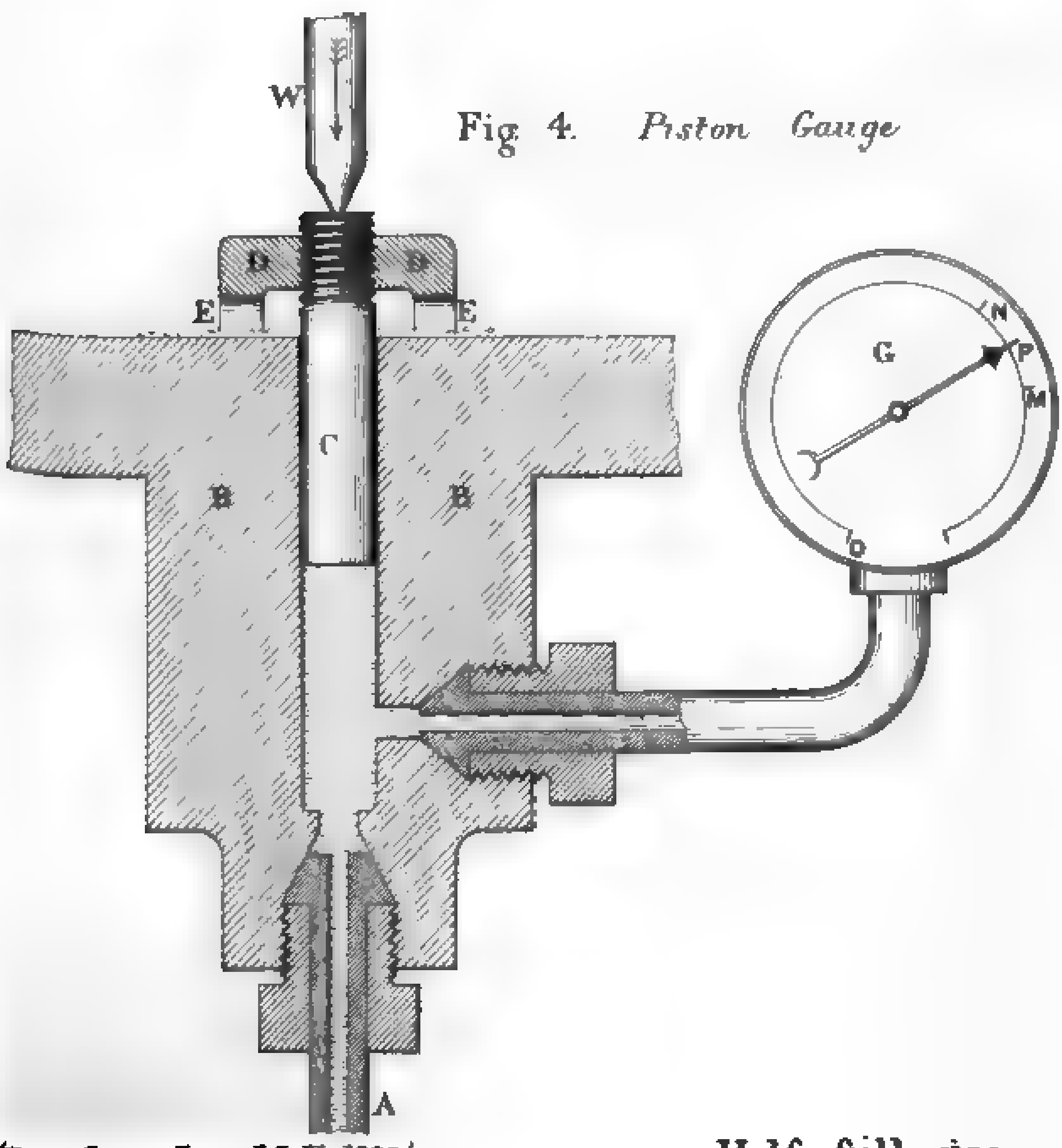


Fig 4. *Piston Gauge*

(Proceedings Inst. M. E. 1880)

Half full size.

Plate 71.

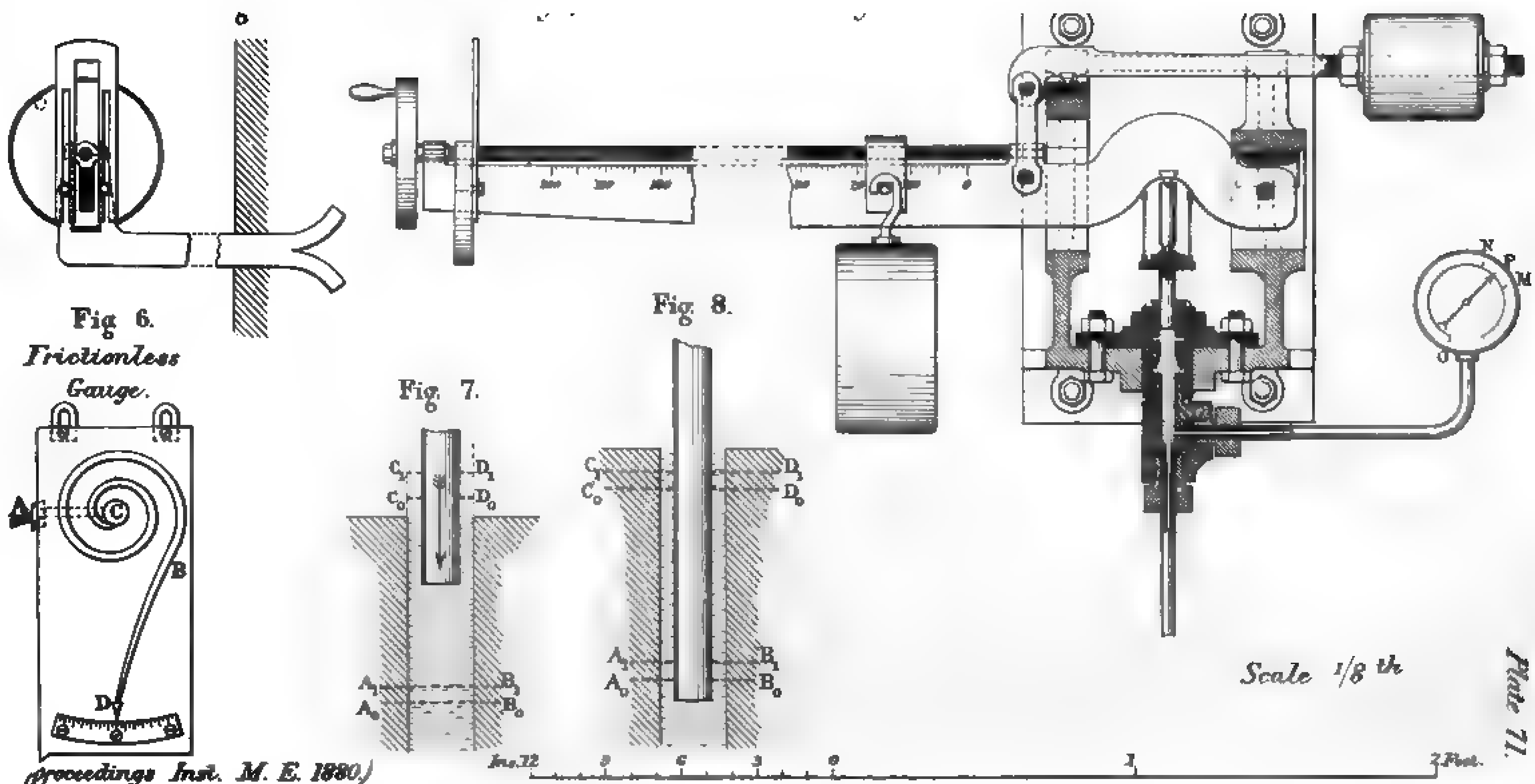


Fig 6. Frictionless Gauge.

Fig 7.

Fig 8.

(Proceedings Inst. M. E. 1880)

COTTON SPINNING MACHINERY. *Plate 72.*

Drawing Frame.

Fig. 1. *Transverse Section*

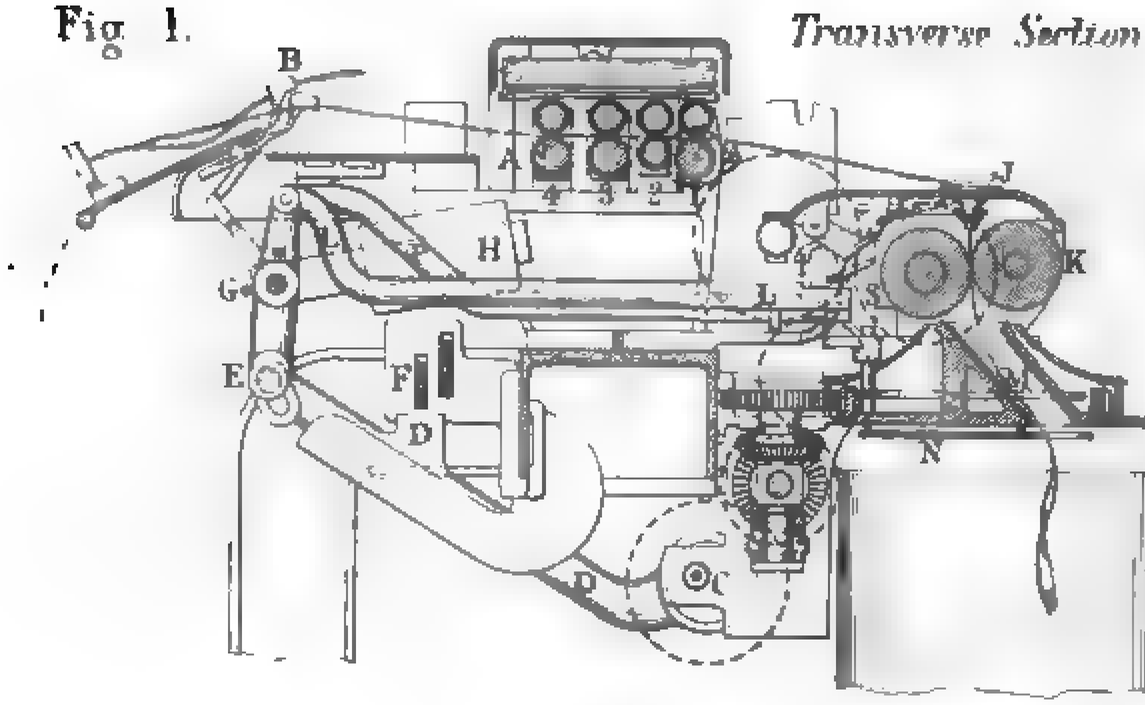


Fig. 2. *Elevation of Gearing*

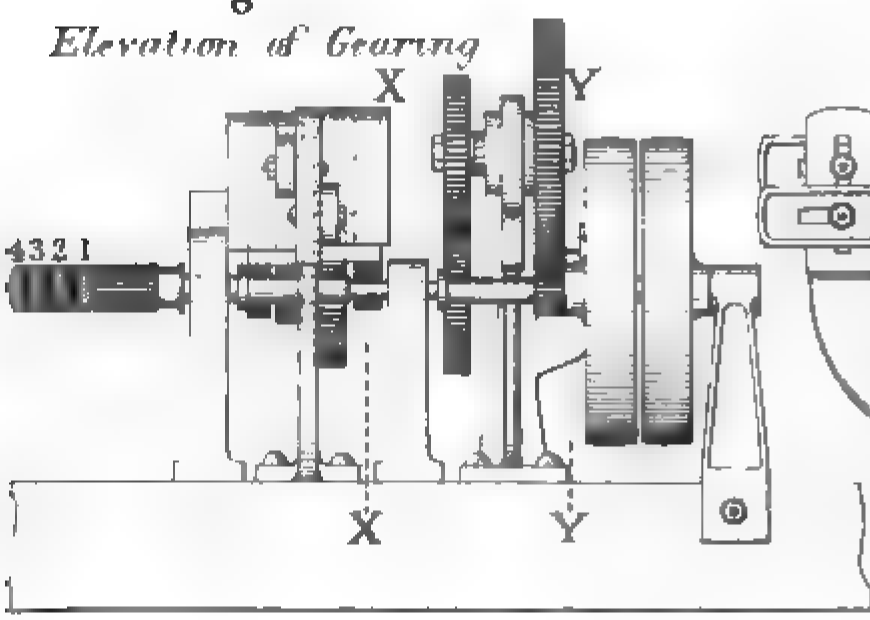


Fig. 3. *Section at XX.*

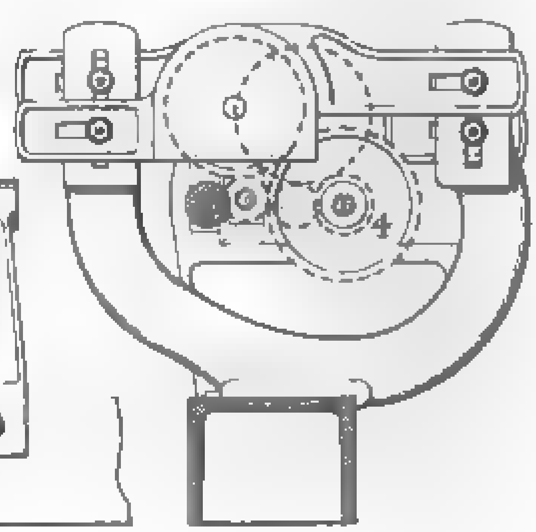


Fig. 4. *Plan of Gearing*

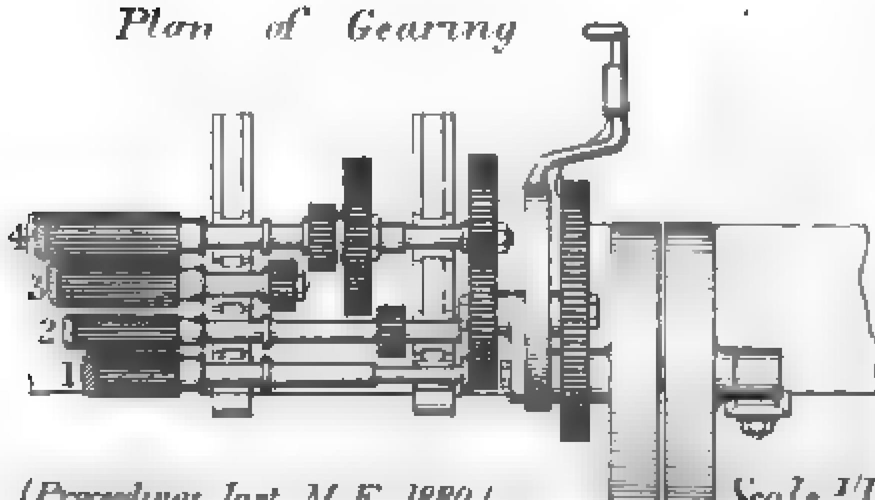
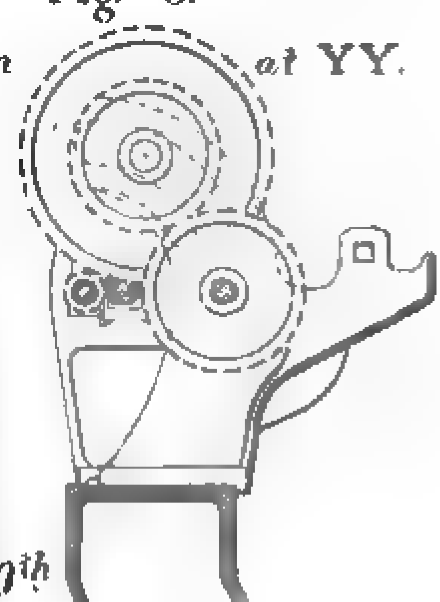


Fig. 5. *Section at YY.*



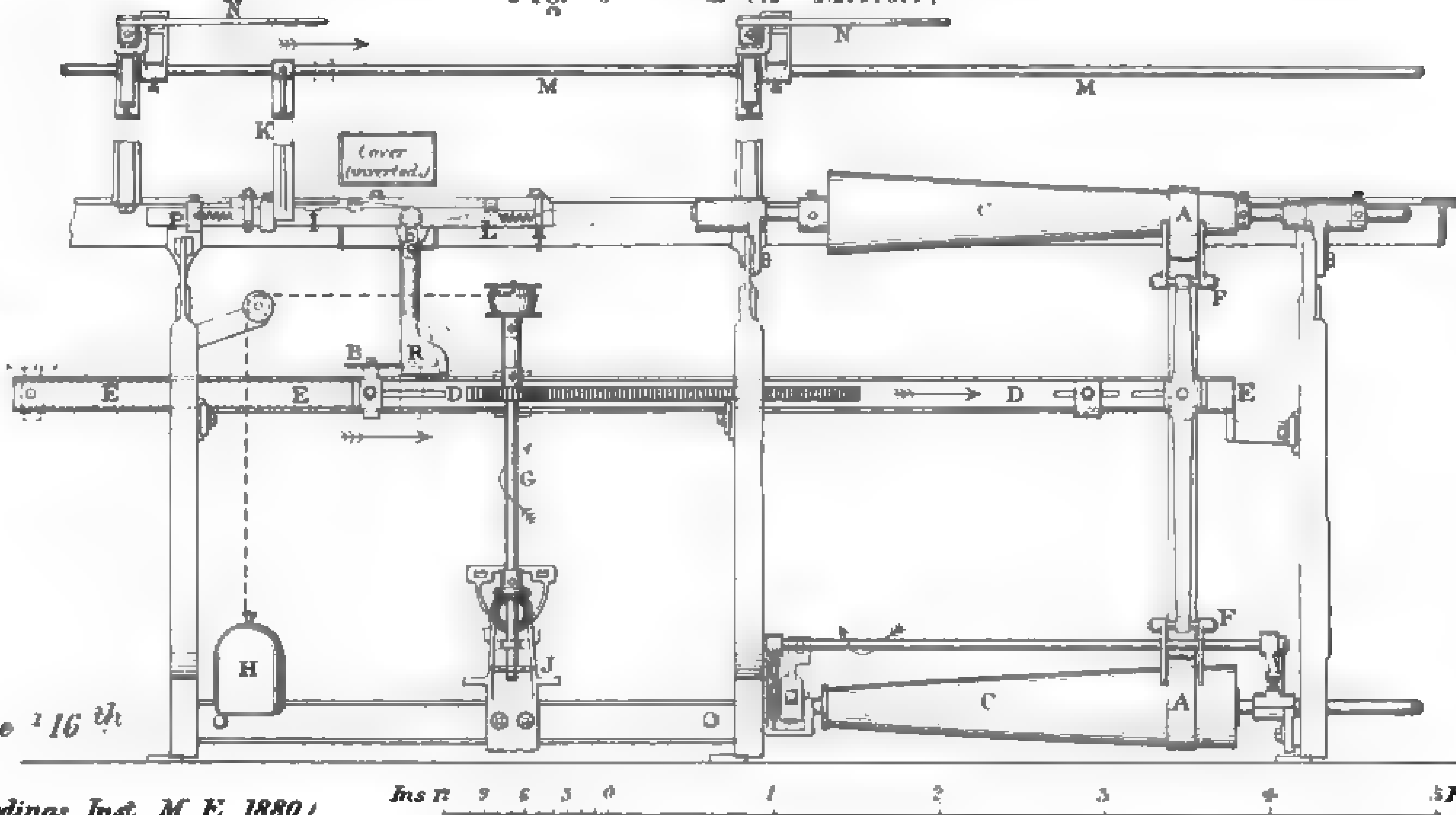
(Proceedings Inst. M. E. 1880) *Scale 1/10th*

Inches 12 9 6 3 0 1 2 Feet.

Plate 73

Slubbing, Intermediate, and Roving Frames.

Fig. 6 *Lock Motion.*



Scale 1/16 th

(Proceedings Inst. M. E. 1880.)

COTTON SPINNING MACHINERY

Self-acting Mule for Medium Counts

Fig. 7. *Backing-off-Chain Tightening Motion.*

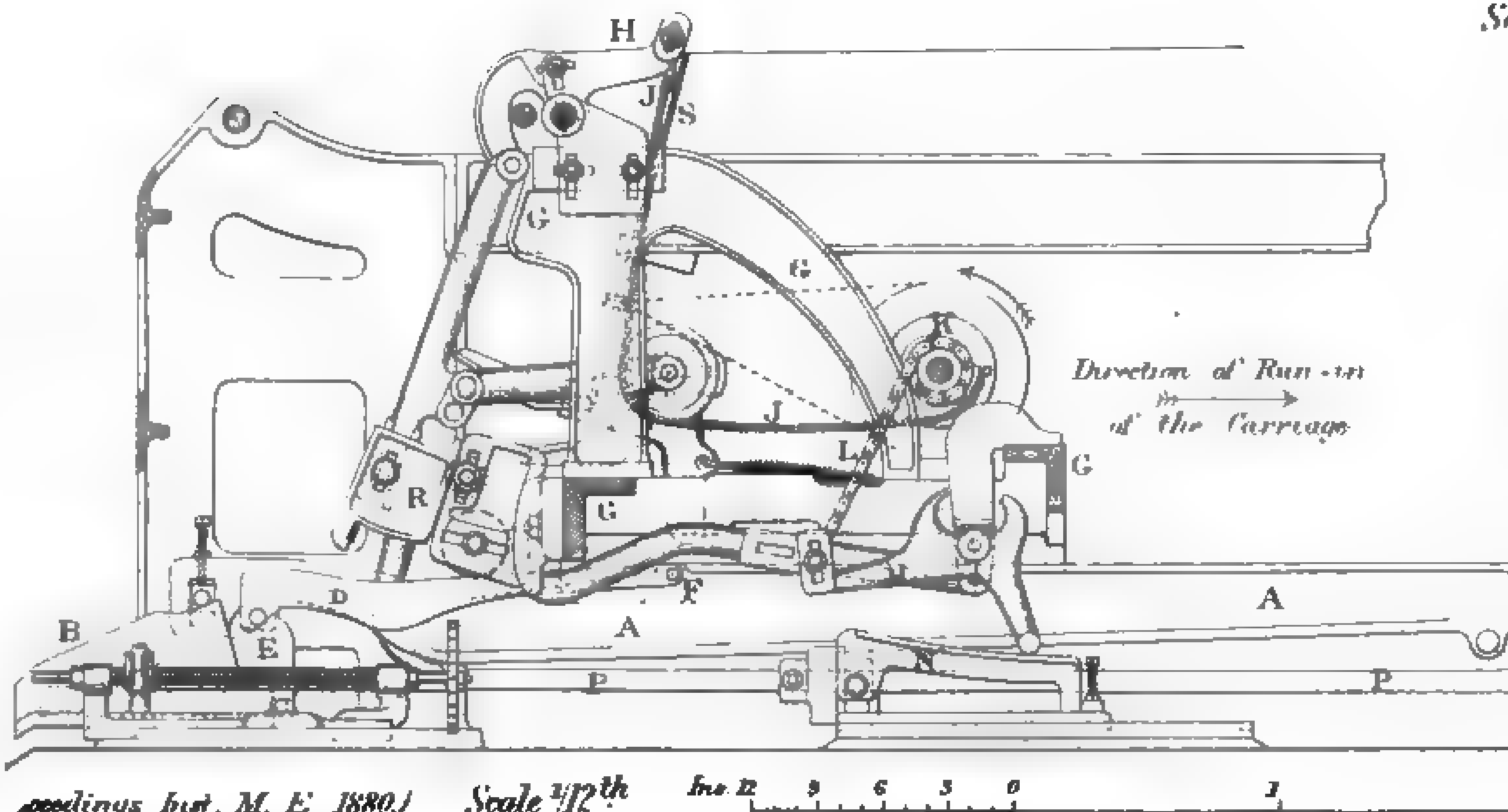


Fig. 8.
Formation of Cop
Scale 1/4th

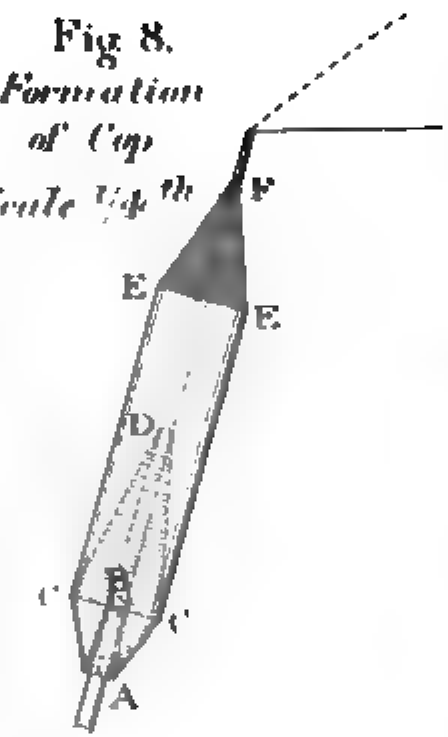


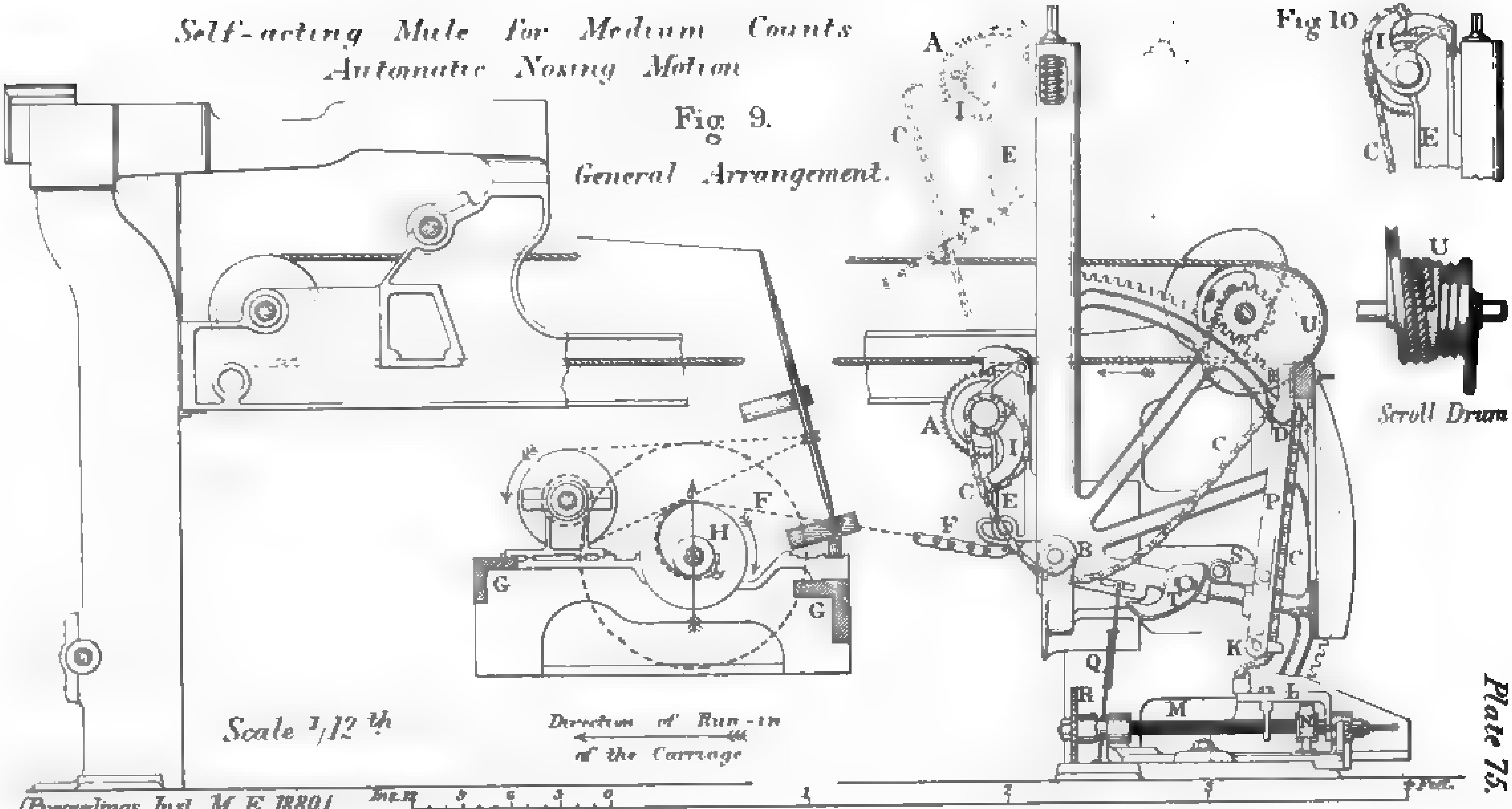
Plate 74

...eedings Inst. M. E. 1880.) *Scale 1/12th*

Self-acting Mule for Medium Counts
Automatic Nosing Motion

Fig. 9.
General Arrangement.

Fig 10



Scroll Drum.

Scale 1/12 th

Direction of Run-in of the Carriage

Plate 75.

Self-acting Mule for Medium Counts

Automatic Nosing Motion

Fig. 11. *Completion of Cop-bottom.*

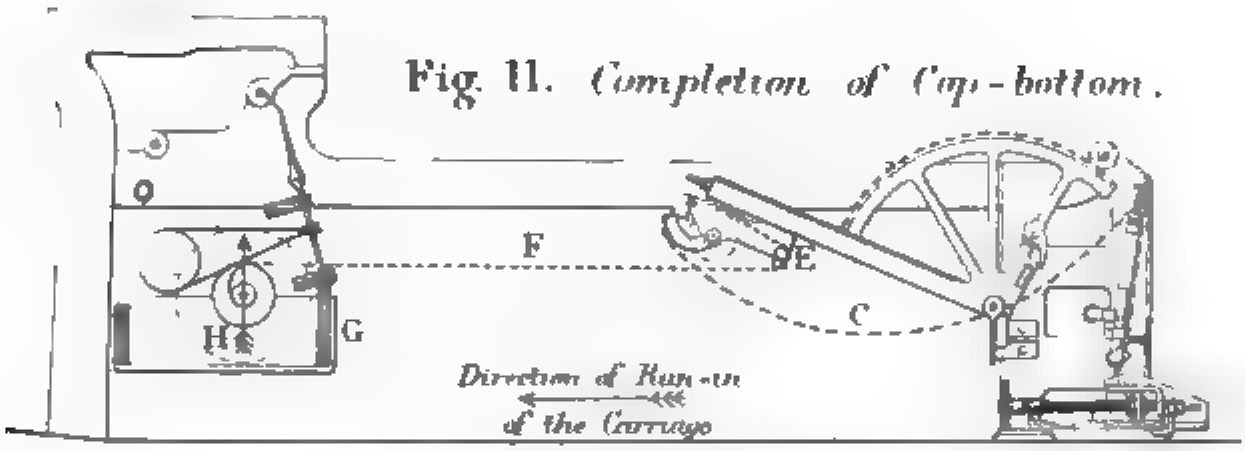


Fig. 12. *Completion of Cop*

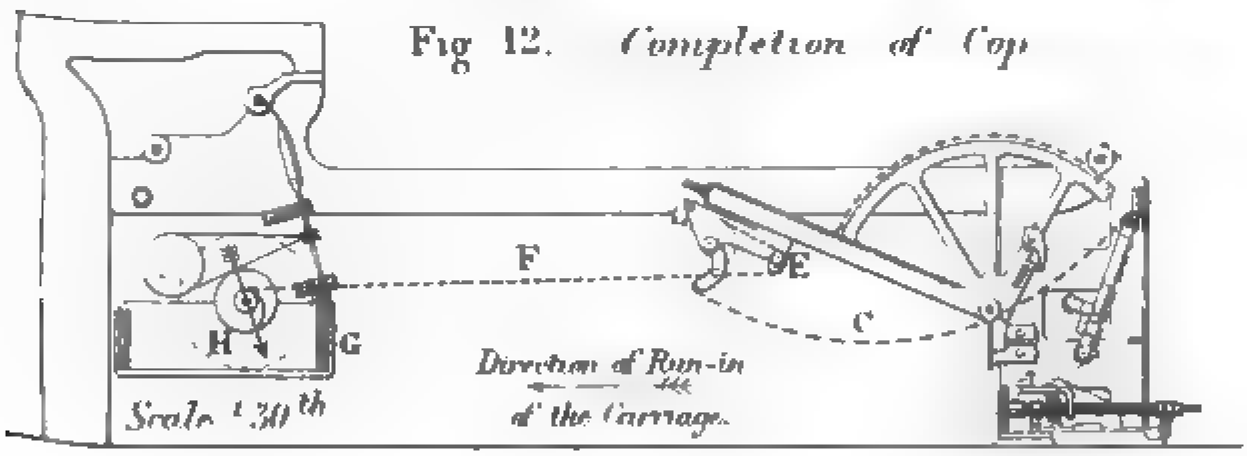
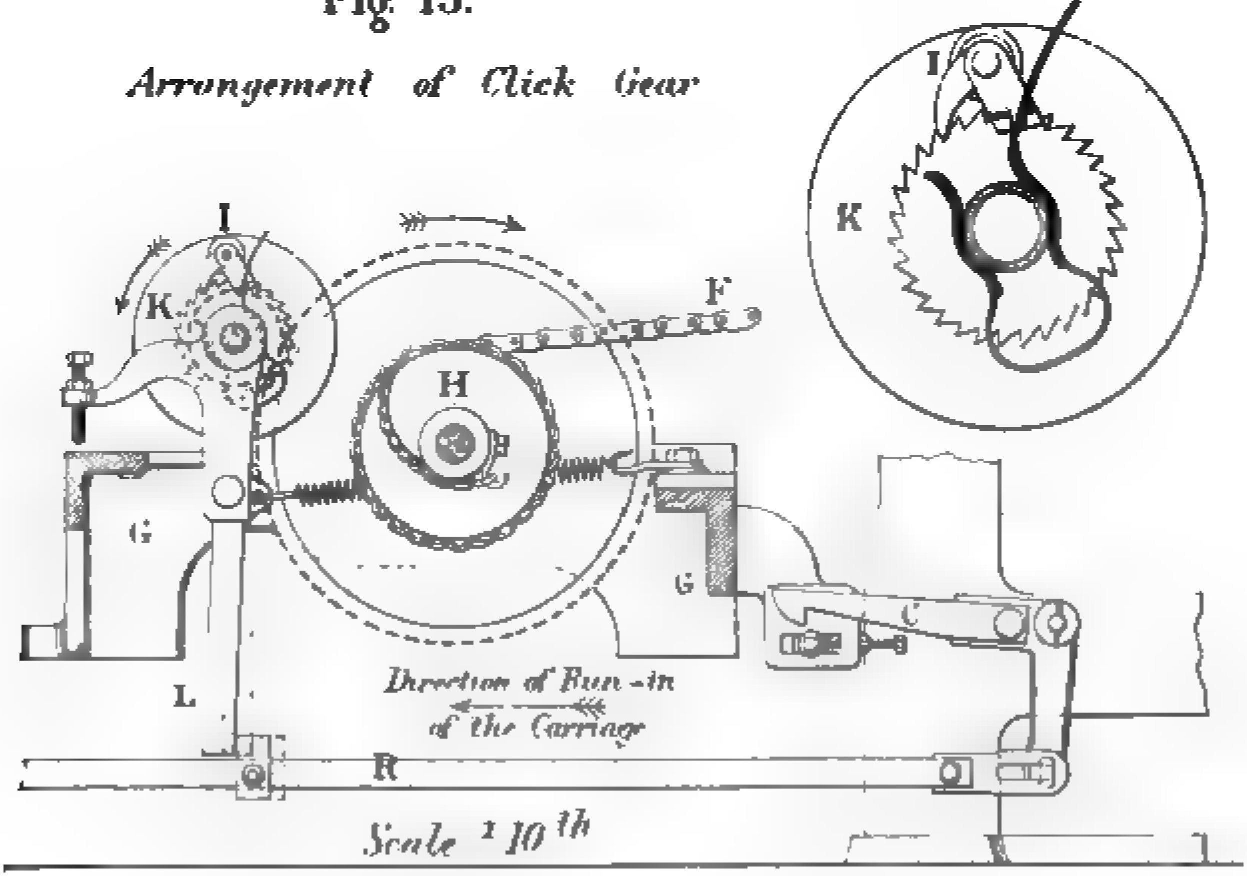


Fig. 13.

Arrangement of Click Gear



Enlargement of Click and Click Wheel

Ins. 12 9 6 3 0 1 2 Feet.

(Proceedings Inst. M. E. 1880.)

[redacted]

Self-acting Mule for Finest Counts.

Fig. 14. *Improved Faller Motion &c*

Scale 1/12th

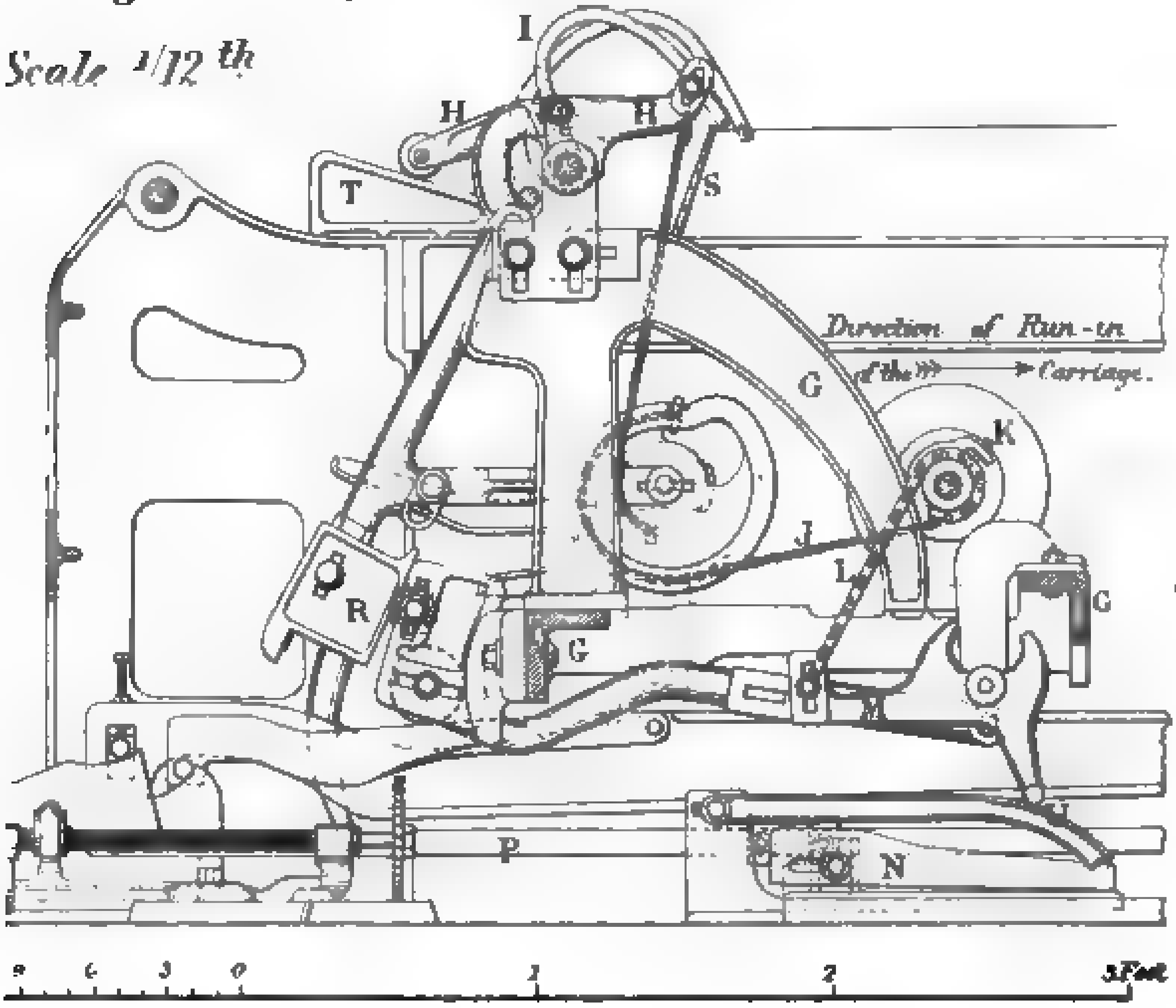
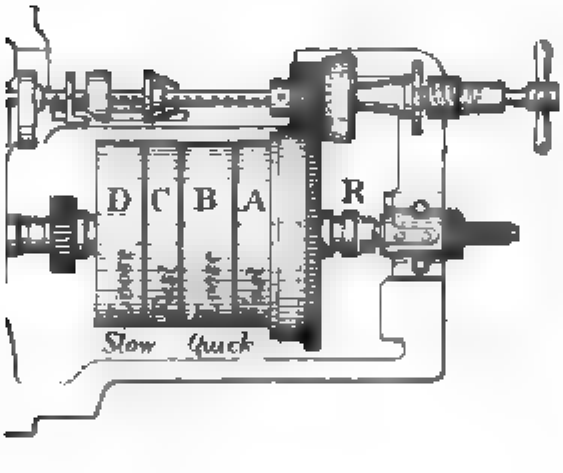


Fig 17.

on of Driving Pulleys for Mule.

Scale 1/24th



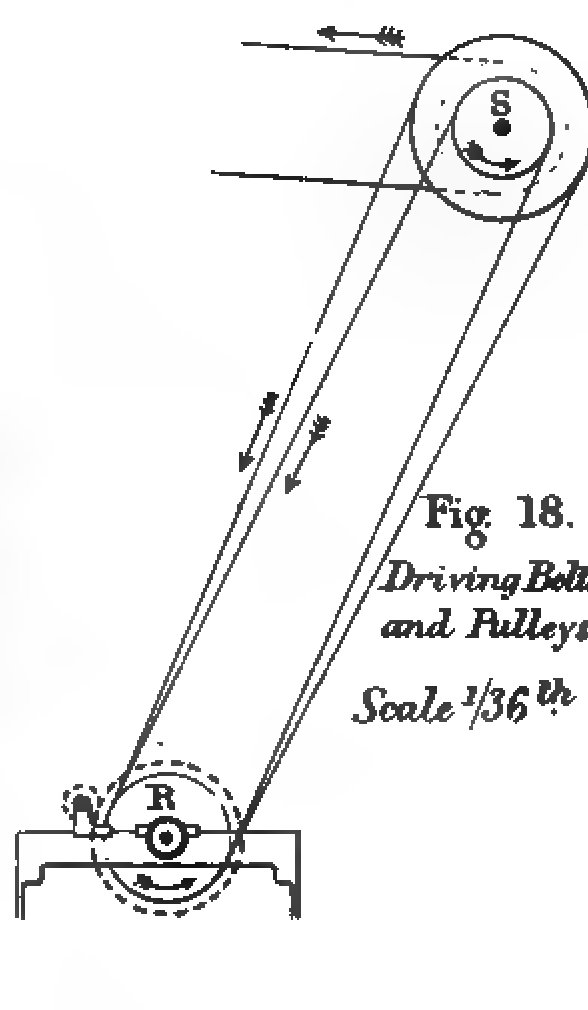


Fig. 18.

Driving Belts and Pulleys.

Scale 1/36th

(...edings Inst. M E. 1880.)

[redacted]

[redacted]

Faller - Lifting Motion.

Fig. 15. *Section*

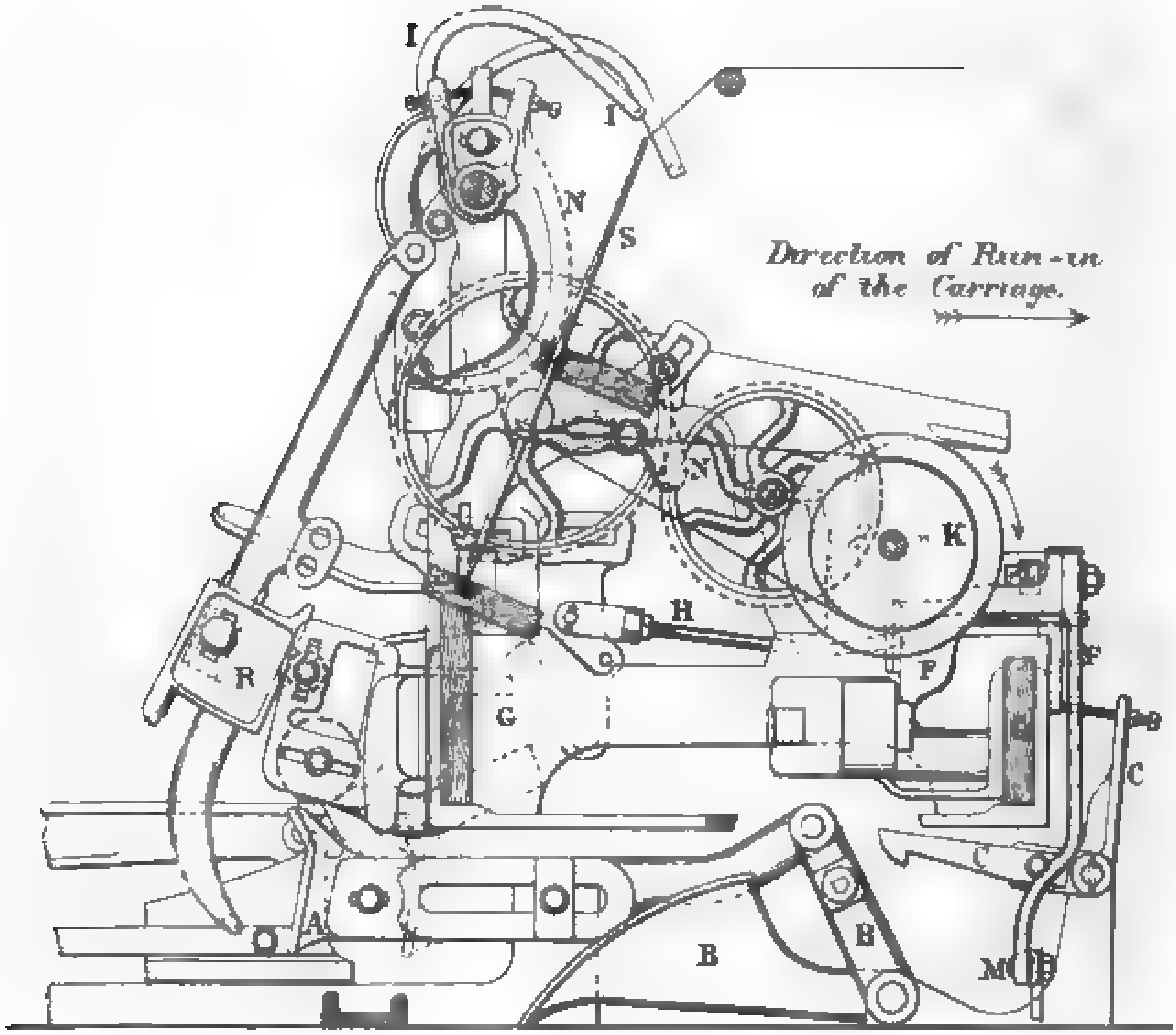
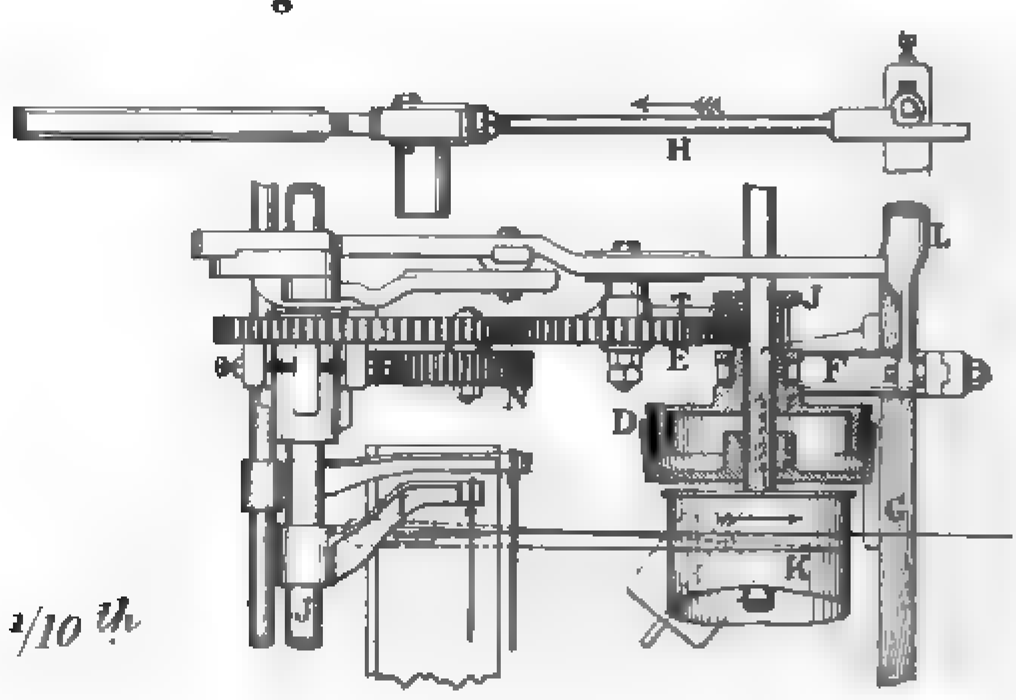


Fig. 16. *Plan.*



Scale 1/10 th

(Proceedings Inst. M. E. 1880.)

CULTIVATION BY HORSES.

Projections of Breast of Plough.

Fig. 3.

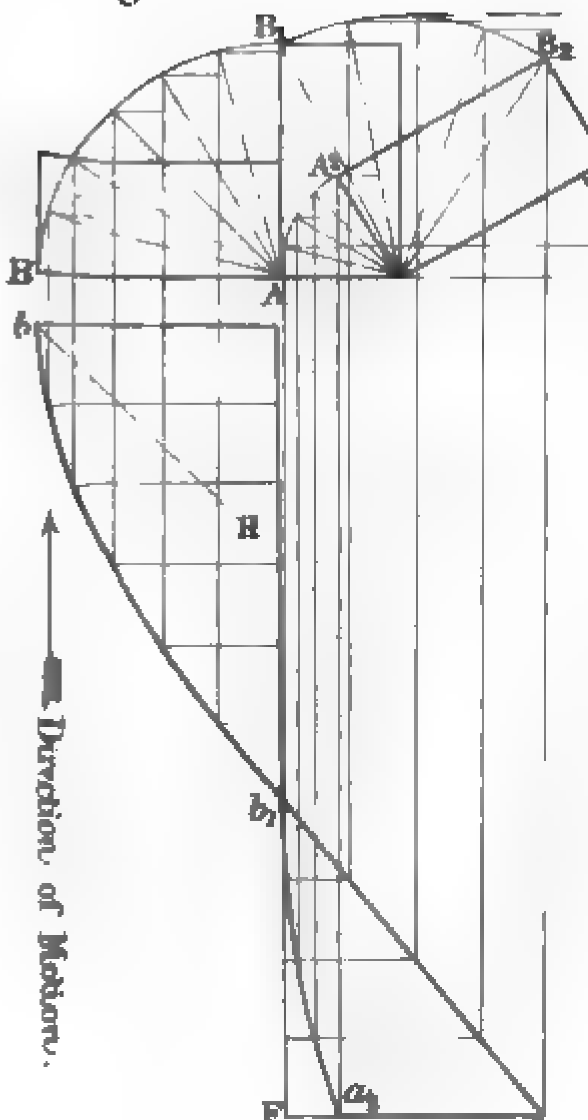
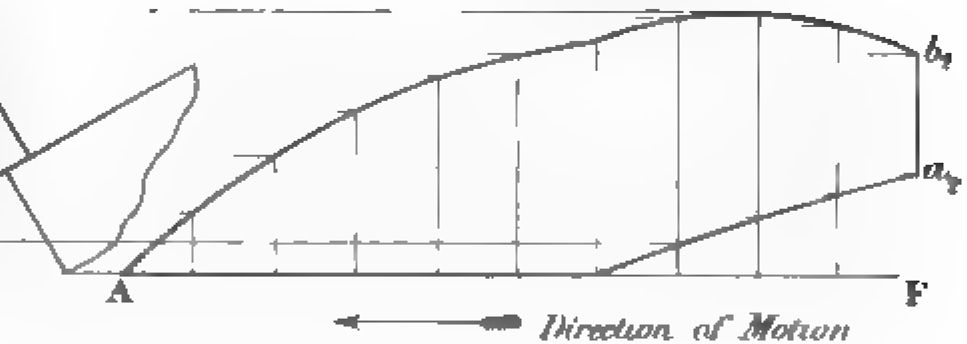



Fig. 4.

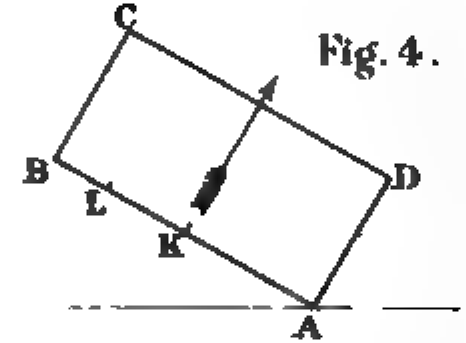


Fig. 1.

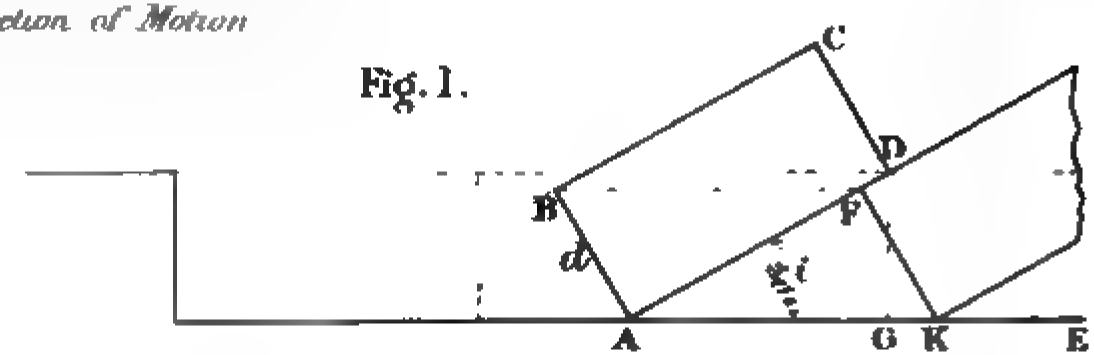


Fig. 5.

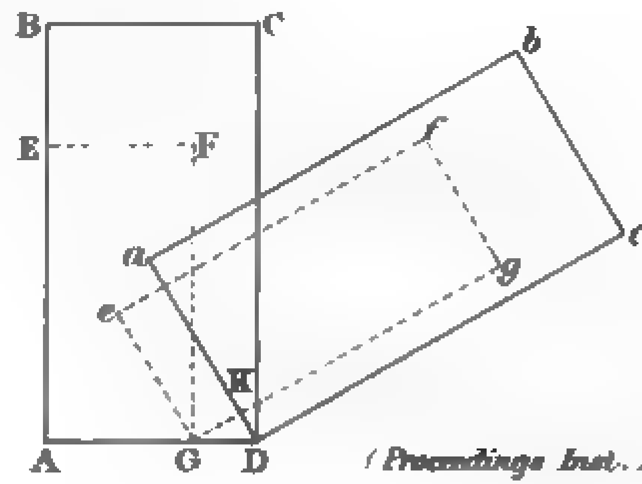
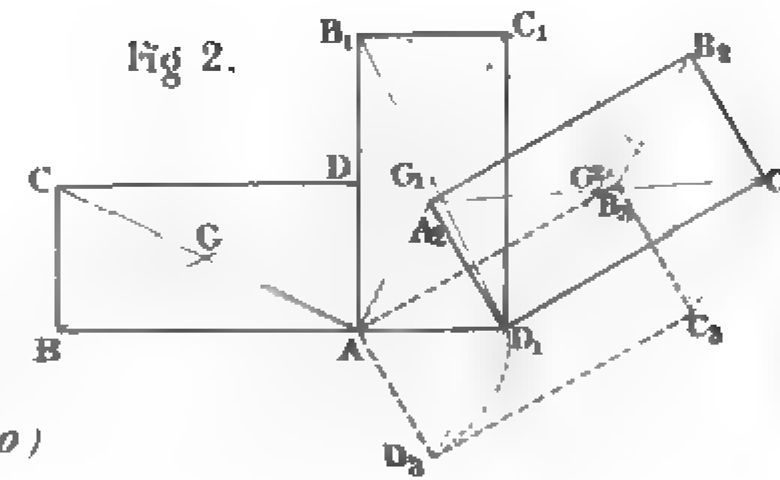


Fig. 2.

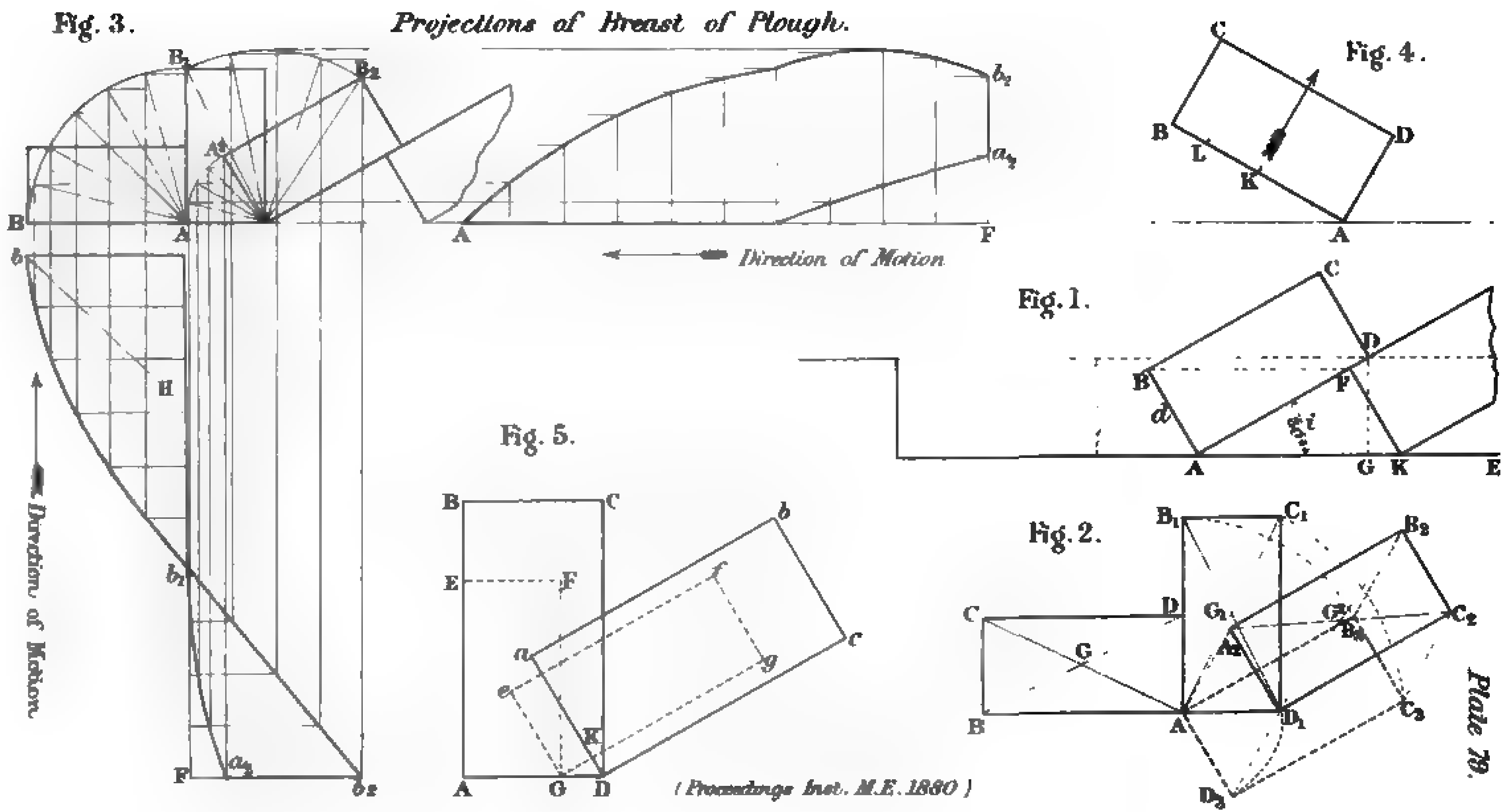


(Proceedings Inst. M.E. 1880)

Plate 79.

CULTIVATION BY HORSES.

Projections of Breast of Plough.



(Proceedings Inst. M.E. 1880)

Fig. 6. *Howard's "Simplex" Plough.*

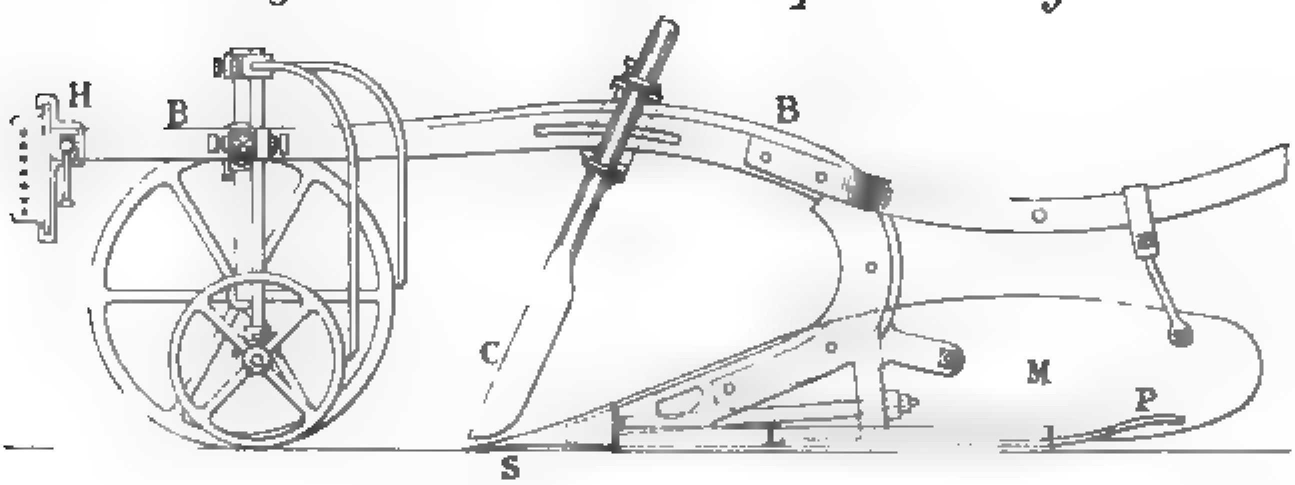


Fig. 7. *Plan.*

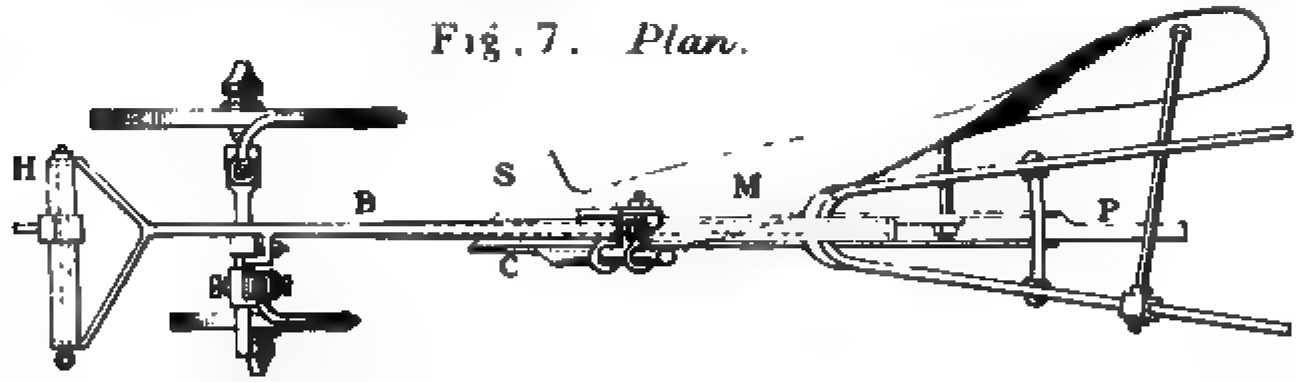


Fig. 8. *Ransomes' "Newcastle" Plough.*

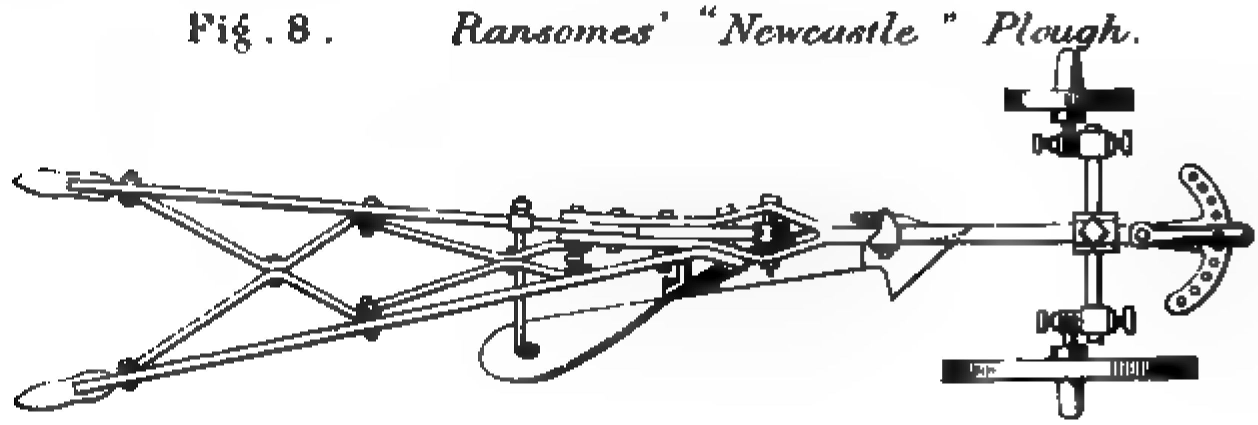


Fig. 9. *Hornsby's "R.B." Plough*

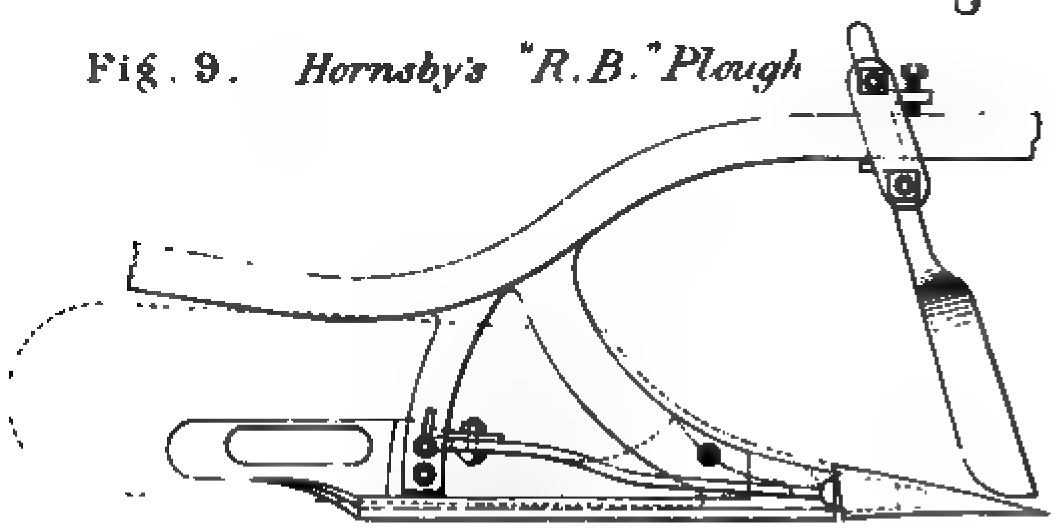
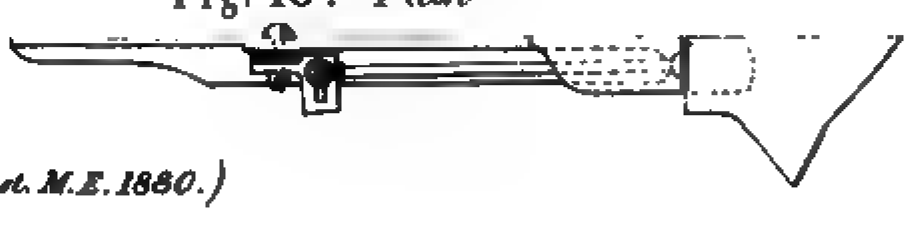


Fig. 10. *Plan*



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